METC/CR-79/2

DEVONIAN SHALES OF OHIO AND THEIR EASTERN AND SOUTHERN EQUIVALENTS

By
Joseph F. Schwietering

January 1979

Work Prepared under Contract No. EY-76-C-05-5199

By

West Virginia Geological and Economic Survey
Morgantown, West Virginia

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $5.25
Microfiche $3.00

Printed in the United States of America
USDOE Technical Information Center, Oak Ridge, Tennessee

METC/CR-79/2
Distribution Category UC-92

DEVONIAN SHALES OF OHIO AND THEIR EASTERN AND SOUTHERN EQUIVALENTS

January 1979

Joseph F. Schwietering

Prepared for
UNITED STATES DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, W. Va.

By

West Virginia Geological and Economic Survey
P.O. Box 879
Morgantown, West Virginia

under

Contract EY-76-C-05-5199

CONTENTS

ILLUSTRATIONS

DEVONIAN SHALES OF OHIO AND THEIR

EASTERN AND SOUTHERN EQUIVALENTS

by

Joseph F. Schwietering

West Virginia Geological and Economic Survey

Abstract

Devonian shale units recognized in outcrops in Ohio can be identified in the subsurface of eastern Ohio and eastern Kentucky and can be traced into Pennsylvania, New York, and West Virginia by means of gamma ray-neutron and sample-description logs. An unconformity separates the Olentangy Shale into two parts; the lower part is equivalent to part of the Hamilton Group of the eastern states, the upper part is equivalent to the Java and West Falls Formations of New York. The unconformity within the Olentangy Shale is the same as the unconformity separating the Tully Limestone from the underlying Hamilton Group in the eastern areas. The Ohio Shale of Ohio is equivalent to the Conewango, Conneaut, and Canadaway Groups of New York and the Chattanooga Shale of Kentucky.

INTRODUCTION

The sediments that make up the Middle and Upper Devonian shales of Ohio were deposited in broad intercontinental seas and are the western equivalents of rocks of marine and continental origin that make up the Catskill Delta in New York, Pennsylvania, Maryland, and West Virginia. The purpose of this study was to establish physical correlations between the Devonian shales exposed in Ohio and their equivalents in states to the east and south by tracing these rocks in the subsurface.

Devonian rocks in Ohio and to the east and south have been known and studied for more than 100 years. Much of the early work is summarized in the following papers, which contain reviews of the history and usage of the stratigraphic names applied to these rocks. Prosser (1903a, 1905) listed and described all the formations recognized in Ohio. Pepper and others (1954, p. 11-17) briefly described the Ohio Shale, its members, and its correlatives in northwestern Pennsylvania. Hoover (1960) reviewed the stratigraphic terms applied to the Devonian and Mississippian shales and included an annotated bibliography. Caster (1934) described the Upper Devonian rocks in northwestern Pennsylvania. Willard and others (1939) discussed the Devonian rocks in Pennsylvania, primarily those exposed in the eastern and southern parts of the state. A volume edited by Shepps(1963) contains many papers on the Devonian of Pennsylvania and surrounding states. Cooper (1930, 1933, 1934) described the Hamilton Group of New York. Rickard (1964, 1975), in correlation charts of the Devonian rocks of New York showed the stratigraphic names applied to these rocks and the lateral lithologic variations in the section. His charts are summarized in Figure 7 of this paper. Woodward (1943) described the Devonian rocks of West Virginia. Savage (1930) and Twenhofel (1931) discussed the Devonian of Kentucky. Friedman and Johnson (1966) summarized existing knowledge of the Catskill Delta. Fettke (1933, 1961) and Martens (1939, 1945) published descriptions of cuttings from many wells drilled in the area of study. Wallace and others (1977, 1978) have published subsurface cross sections of Devonian rocks in the Appalachian basin.

METHOD OF STUDY

Data used in this study were obtained from measurement of 12 outcrops in Ohio, 132 gamma ray-neutron logs, and 29 well-sample logs. Cuttings from 28 wells drilled in Ohio were examined. The locations of the measured sections and wells are shown on figure 1. Wells used in constructing the cross sections and fence diagrams are listed in Appendix A.

In Ohio, Middle and Upper Devonian rock units were measured on the outcrop. These units were then identified on gamma ray-neutron logs and on sample logs of wells drilled near the outcrops. Published information of rock units was relied on for New York, Pennsylvania, West Virginia and Kentucky (Donnerstag and others, 1950, 1952; Fettke, 1933, 1961; Martens, 1939, 1945). The rock stratigraphic units were traced by means of geophysical and sample logs, and their lateral relations were established.

Dark carbonaceous shale in the Devonian section can be distinguished on gamma ray-neutron logs by higher radioactive values than those of lighter colored shale, siltstone, sandstone, and limestone (fig. 2). The radioactivity is the result of the emission of gamma rays by unstable isotopes of uranium, thorium, and potassium. Uranium is the primary source of gamma rays in these shales, although thorium has been reported (Hoover, 1960, p. 62) and potassium is present in the silt-sized feldspar grains and clay minerals. Bates (1957), in a study of uranium in the black carbonaceous Chattanooga Shale of Tennessee, showed that uranium is randomly distributed in the unaltered rock and is associated with organic material and pyrite. The

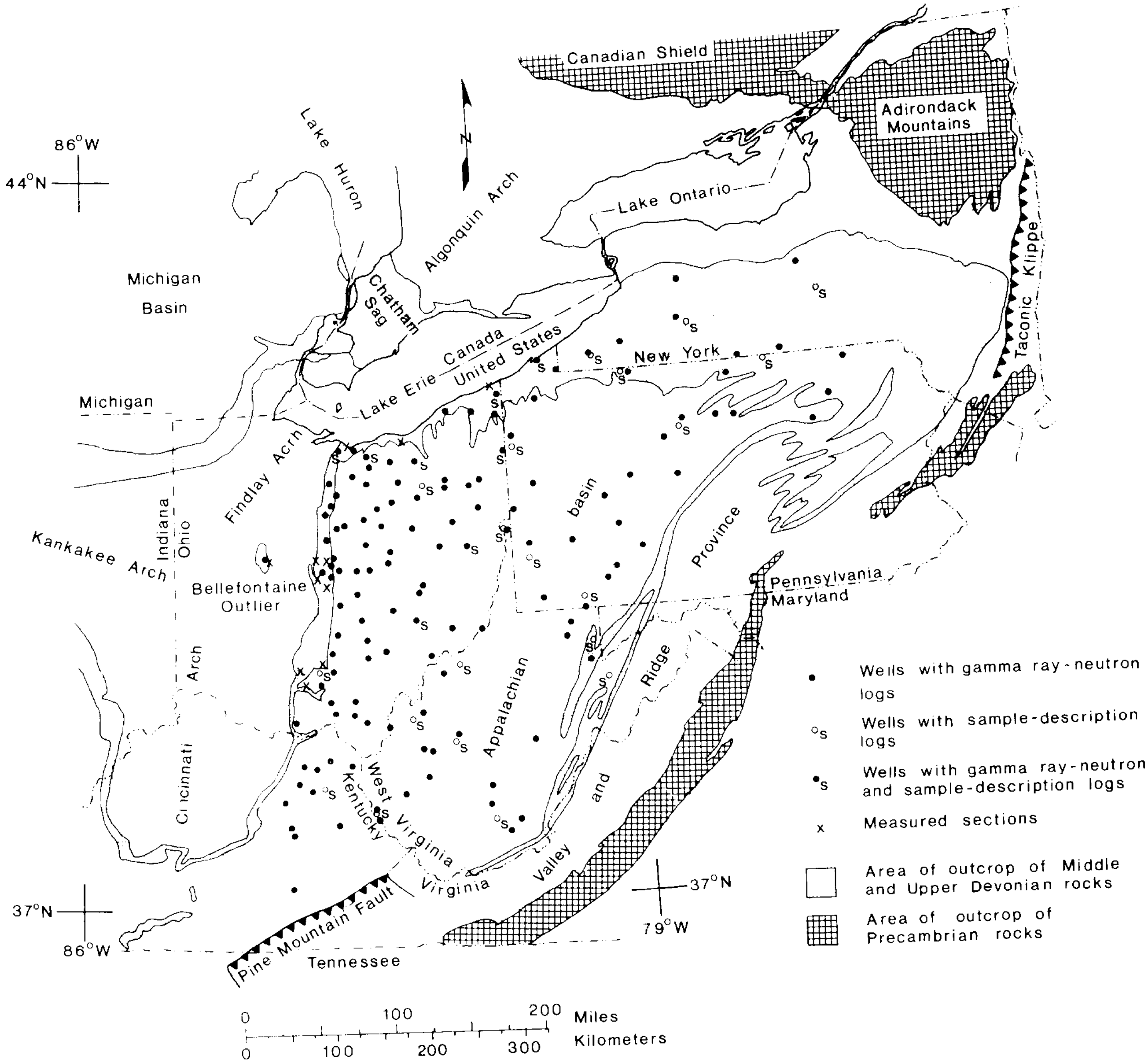


Figure 1.

Structural features of the study area and location of wells and measured sections used in the study.

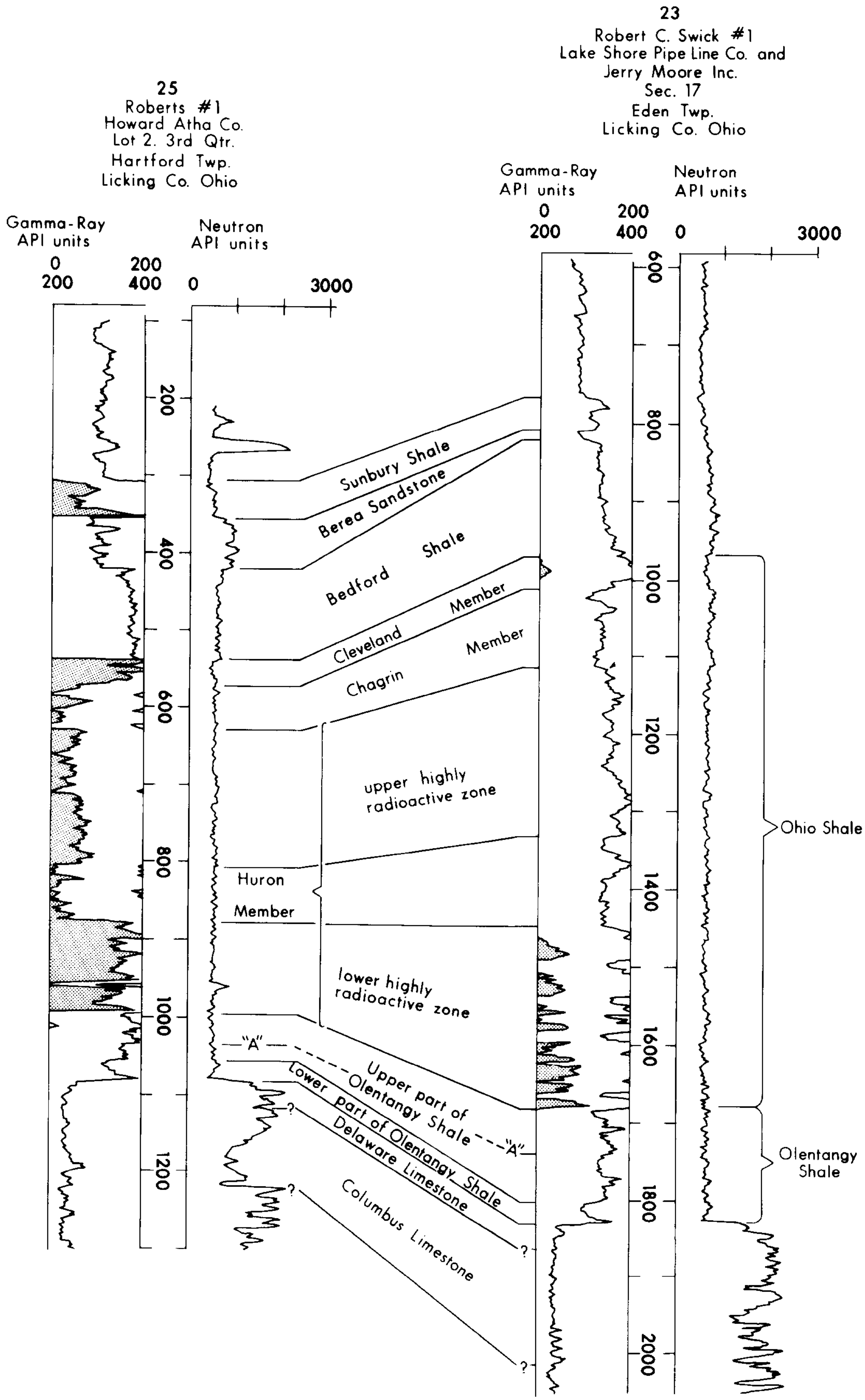


Figure 2.
Typical gamma ray-neutron logs of wells drilled through the Devonian shales of central Ohio.

random distribution of the uranium suggests that it was precipitated from sea water.

Rock units may be readily traced on gamma ray-neutron logs in eastern Ohio and eastern Kentucky, where dark carbonaceous shales are present. Good results were also obtained in tracing rock units of the Middle Devonian sequence and the lower part of the Upper Devonian sequence of New York and western Pennsylvania. Results were poor, however, in tracing rock units of the Middle and Upper Devonian sequence of eastern and southern Pennsylvania and much of West Virginia and the upper part of the Upper Devonian in New York and western Pennsylvania because of the absence of highly radioactive shales.

GEOLOGIC SETTING

The major structural elements that are thought to have affected sedimentation during the Devonian in Ohio and adjacent states are shown in figure 1.

The area of study lies within the Appalachian basin (Appalachian Plateaus Province), a structurally low region west of the complexly folded and faulted Appalachian Mountains (Valley and Ridge Province) and east of the Cincinnati, Findlay and the Algonquin Arches. The Canadian Shield and the Adirondack Mountains bound the basin to the north. The basin extends southwest from central New York to Alabama, and contains a suite of rocks, Paleozoic in age, that were deposited in a miogeosyncline. These Paleozoic rocks form a wedge that thickens eastward from Ohio and central Kentucky into Pennsylvania, New York and West Virginia. The clastic rocks that make up the Middle and Late Devonian Catskill Delta are part of this wedge of Paleozoic sedimentary rocks. The Catskill Delta was built westward into the Appalachian basin from highlands to the east of the present Appalachian Mountains. The exact location and geologic nature of the eastern source area are not known.

The Cincinnati Arch is a major structural element which extends north from the Nashville Dome in central Tennessee through central Kentucky, western Ohio, and eastern Indiana. In west-central Ohio the Cincinnati Arch bifurcates into the Kankakee Arch, which extends northwest, and the Findlay Arch which extends northeast (fig. 1). In southwestern Ontario the Findlay

Arch is crossed by the Chatam Sag, a structural low that provided a passage through which water from the Michigan basin and the Appalachian basin joined during periods of major Paleozoic transgressions of the sea. The Algonquin Arch extends northeast from the Chatam Sag. The Cincinnati and Findlay Arches probably contributed some sediment to the Appalachian basin during periods of marine regression.

North of the region of study are the Canadian Shield and the Adirondack Mountains. The shield may have been the source of some of the sediments that were deposited in the basin during the Devonian, but the thickness and character of Devonian rocks along the northern outcrops, and Fuller's report (1950) of Middle Devonian limestone pebbles derived from a northern source in the Sharon Conglomerate (Pennsylvanian) of northern Ohio, suggest that some, if not all, of the Canadian Shield was covered by the sea at times during the Devonian.

Evidence of the prominence of the Adirondack Mountains during the Devonian is inconclusive. Isopach maps of Lower Devonian rocks in New York (Oliver and others, 1967, p. 1008-1011) suggest that these mountains were structurally high during the Early Devonian. However, the thickness and lithofacies distribution of Middle and Upper Devonian rocks to the south of the mountains do not indicate the the Adirondacks markedly affected sedimentation during the Middle and Late Devonian (Oliver and others, 1967, p. 1012-1017; this paper fig. 8, 10, 11, 12). Petrographic studies of the Tully Limestone suggest that some of the clastic material in the Tully may have come from the Adirondack Mountains. Trainer (1932, p. 28-29) suggests that plagioclase particales in the Tully came from igneous rocks in the Adirondacks. Heckel (1969, p. 21-25) suggests that carbonate shoals existed to the north of the present outcrops of the Tully Limestone in New York, and that these shoals supplied fine carbonate mud for the Tully Limestone.

OLENTANGY SHALE AND EQUIVALENTS

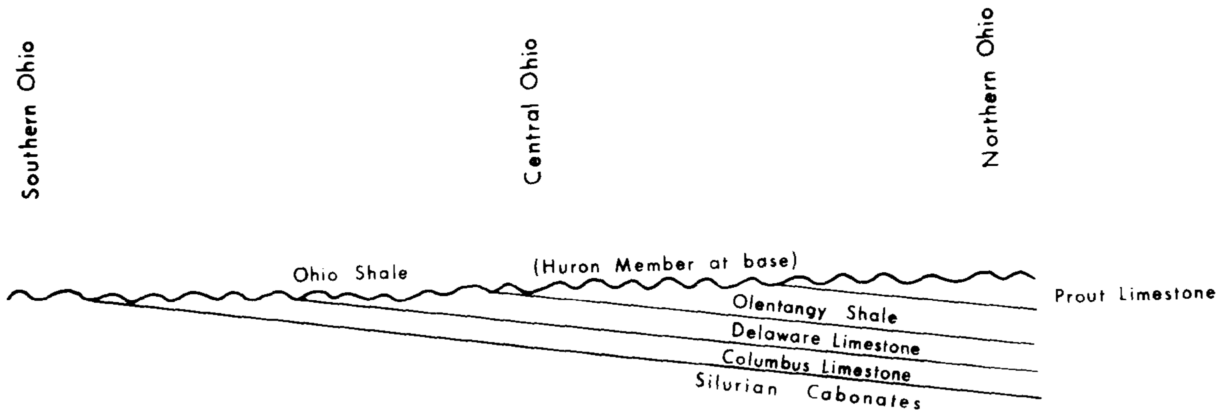
Description and nomenclature

Winchell (1874, p. 287) first applied the name "Olentangy shale" to "bluish and sometimes greenish shale which is so extensively exposed in banks of the Olentangy River, in Delaware county, and which underlies the black, tough, but thin beds of the Huron shale. It has a thickness of about 30 feet."

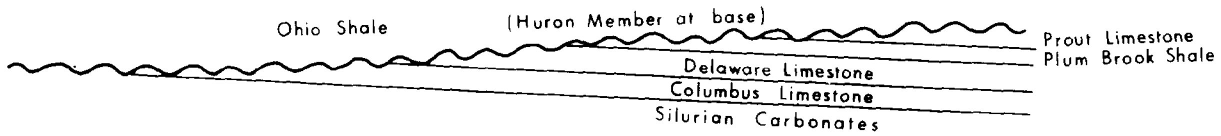
Hoover (1960, p. 11) described the Olentangy Shale in central Ohio as "chiefly a bluish-gray to greenish-gray clay shale with black fissile shale beds in the upper portion. It is characterized by flat concretionary masses of blue limestone; compact limestone layers; and pyrite in the form of small nodular concretions, small grains or crystals, and in disseminated form."

Orton and others (1893, p. 20) described a blue shale exposed at Prout Station, Erie County, Ohio. He believed the shale to be Middle Devonian in age and equivalent to the Olentangy Shale of central Ohio and to the Hamilton Group of New York. The blue shale at Prout Station is overlain by a limestone bed to which Stauffer (1916) formally applied the name Prout Limestone (a name informally used by Prosser, 1903a, p. 47). The blue shale rests on Middle Devonian limestone. The Prout Limestone is unconformably overlain by the Huron Member of the Ohio Shale (Stauffer, 1916, p. 485-486; Grabau, 1917, p. 338).

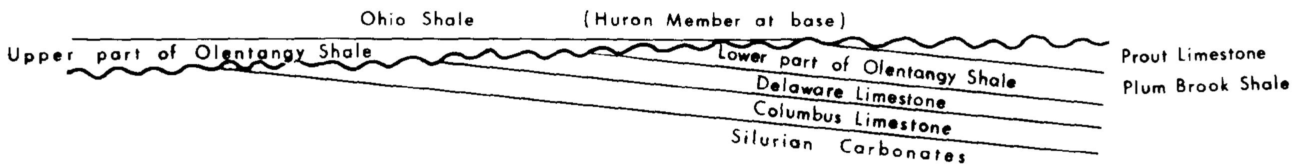
Stauffer (1916) correlated the blue shale at Prout Station with the



A. An interpretation of text by Stauffer, 1906, p. 476-487.



B. Modified from Grabau, 1917, p. 342, fig. 1.



C. This paper.

Figure 3.

Three concepts of the relationship of the Olentangy Shale to overlying and underlying rocks. Drawings are not to scale.

Olentangy Shale of central Ohio (fig. 3a) and the Arkona Shale of southwestern Ontario; he also correlated the Prout Limestone with the Hungry Hollow (Encrinal) Limestone of Ontario. He considered all these formations to be Middle Devonian in age and equivalent to the Hamilton Group.

Grabau (1917) proposed the name Plum Creek for the blue shale beneath the Prout Limestone. Cooper (1941) changed this name to Plum Brook Shale. Grabau agreed with Stauffer (1916) in considering the Prout and the Plum Brook to be Middle Devonian in age, equivalent to the Hamilton of New York, and correlatives of the Hungry Hollow and Arkona of southwestern Ontario. However, he did not consider the Prout Limestone and the Plum Brook Shale to be equivalent to the Olentangy Shale of central Ohio (fig. 3b), but believed the Olentangy to be a basal phase of the Ohio Shale, of Late Devonian age. Grabau did not recognize an unconformity between the Ohio and the Olentangy, but thought that one existed between the Olentangy Shale and the Delaware Limestone (Middle Devonian) in central Ohio, and between the Huron Member of the Ohio Shale and the Prout Limestone in north-central Ohio. Westgate (1926, p. 35-37) reviewed the conflicting ideas of Stauffer (1916) and Grabau (1917) and accepted Grabau's view.

Lamborn (1927, 1929) described sections of the Olentangy Shale in southern Ohio and noted that, in this area, black shale becomes prominent in the Olentangy. Like Grabau (1917), Lamborn considered the Olentangy to be a basal phase of the Ohio Shale and Late Devonian in age. Lamborn also noted an unconformity beneath the Olentangy Shale. The Olentangy rests on Middle Devonian carbonates in central Ohio and on Silurian carbonates in southern Ohio and eastern Kentucky.

Lamborn (1934, p. 357), in describing a light-colored shale above the Middle Devonian limestone (Big Lime of drillers) in the subsurface of eastern

Ohio, wrote, "The stratigraphic position of this light shale suggests that it represents the eastern continuation of the so-called Olentangy shale of surface outcrops. This bed increases in thickness east of the line from central Stark to central Lawrence counties, but it is separated from the Big Lime by a wedge of black or brown shale which thickens to the east. In the deep well drilled on the Jones farm in Warren Township, Belmont county, the Big Lime is immediately overlain by 200 feet of black shale representing this wedge, above which occure the gray shale; while in the test drilled in Island Creek Township, Jefferson county, the Big Lime is overlain by 400 feet of black shale with 775 feet of light shale above it." Lafferty (1941, p. 809-810) considered the thick black shale immediately above the "Big Lime" in southeastern Ohio to be equivalent to the Marcellus Shale of West Virginia.

Louden (1965), in a subsurface study of the Prout Limestone, Plum Brook Shale, and Olentangy Shale, divided the Olentangy into two parts separated by an unconformity. He suggested that the lower part of the Olentangy of central Ohio is continuous with the Plum Brook Shale of northern Ohio, and that the upper part of the Olentangy may pass into the Huron Member of the Ohio Shale in northeastern Ohio.

Age

All who have studied the Prout Limestone and the Plum Brook Shale consider them to be Middle Devonian in age and equivalent to the lower part of the Hamilton Group of New York. However, there has been no unanimity of opinion on the age and stratigraphic relations of the Olentangy Shale. Stauffer (1909, 1916, 1938a, 1938b), on the basis of conodonts and other fossils, believed the Olentangy to be Middle Devonian in age and the correlative of the Plum Brook Shale of northern Ohio. Baker (1942), on the basis of several fossil groups, and Stewart and Hendrix (1939, 1945a, 1945b), on the basis of ostracods, considered the Olentangy Shale to be Late Devonian in age. Cooper and others (1942, p. 1174, and correlation chart), and Oliver and others (1967, p. 1006-1007) divided the Olentangy Shale into two parts, one Middle Devonian in age, the other Late Devonian. Ramsey (1969, p. 18), on the basis of conodonts, suggested that the lower part of the Olentangy Shale in central Ohio is equivalent to the Tully Limestone and therefore Middle Devonian in age. She considered the lower part of the Olentangy Shale to belong to the upper part of the Givetian Series. Tillman (1969, 1970) on the basis of a study of ostracods from the Olentangy Shale of central Ohio suggested that an unconformity divides the Olentangy into two parts. He considered the lower part to be Middle Devonian in age, and the upper part Late Devonian. Gable (1973) studied conodonts from the Olentangy Shale of central and southern Ohio and also divided the Olentangy into two parts. She correlated the lower part with either the Tully Limestone (upper Givetian) or the Hamilton Group (upper Eifelian to upper Givetian). She correlated the upper part of the Olentangy Shale with the Hanover Shale Member of the Java Formation and the Dunkirk Shale Member of the Perrysburg Formation of New York and therefore Late Devonian in age (upper Frasnian and lower Famennian). She did not report correlatives of the Genesee, Sonyea, and West Falls Formations in the Olentangy Shale of central and southern Ohio. In New York, the Genesee, Sonyea, and West Falls Formations lie between the Tully Limestone and the Java Formation.

The Olentangy Shale is here divided into two parts separated by an unconformity (figs. 3c and 4). These two parts can be recognized on gamma ray-neutron logs (fig. 2), in well-cuttings, and on the outcrop (Louden, 1965; Tillman, 1969, 1970). The lower part, of Middle Devonian age, is equivalent to the Plum Brook Shale of northern Ohio and part of the Hamilton Group of New York. The upper part, of Late Devonian age, is equivalent to the West Falls and Java Formations of New York (fig. 5).

Correlation

Lower part of the Olentangy Shale The lower part of the Olentangy Shale of central Ohio and its northern equivalent, the Plum Brook Shale, are western extensions of part of the Hamilton Group (Middle Devonian) of New York and its equivalents to the south in Pennsylvania and West Virginia (Plate I, B-B' and Plate II, C-C' and D-D'). In central Ohio, Tillman (1970, p. 212-215) recognized a disconformity between the lower part of the Olentangy Shale and the underlying Delaware Limestone (Middle Devonian). Traced eastward into the subsurface, the contact between the lower part of the Olentangy and the underlying Middle Devonian carbonates appears to be conformable. In the northern and western parts of the study area, the Prout Limestone, lower part of the Olentangy and the Hamilton Group are overlain unconformably by younger rocks (Grabau, 1917, p. 338, 341; Huddle, 1974; Rickard, 1964, 1975). An unconformity is not recognized at the top of the Hamilton Group in Pennsylvania or West Virginia (Dennison and Naegle, 1963, p. 16; Ellison, 1965, p. 39; Heckel, 1969, p. 12).

Blue shale and limestone of the Plum Brook Shale (lower part of the Olentangy Shale) are about 26 feet thick near Prout Station southeast of Sandusky in north-central Ohio (Stauffer, 1916, p. 477-478). The unit thins to the south and is absent in southern Ohio (Grabau, 1917, p. 341-343;

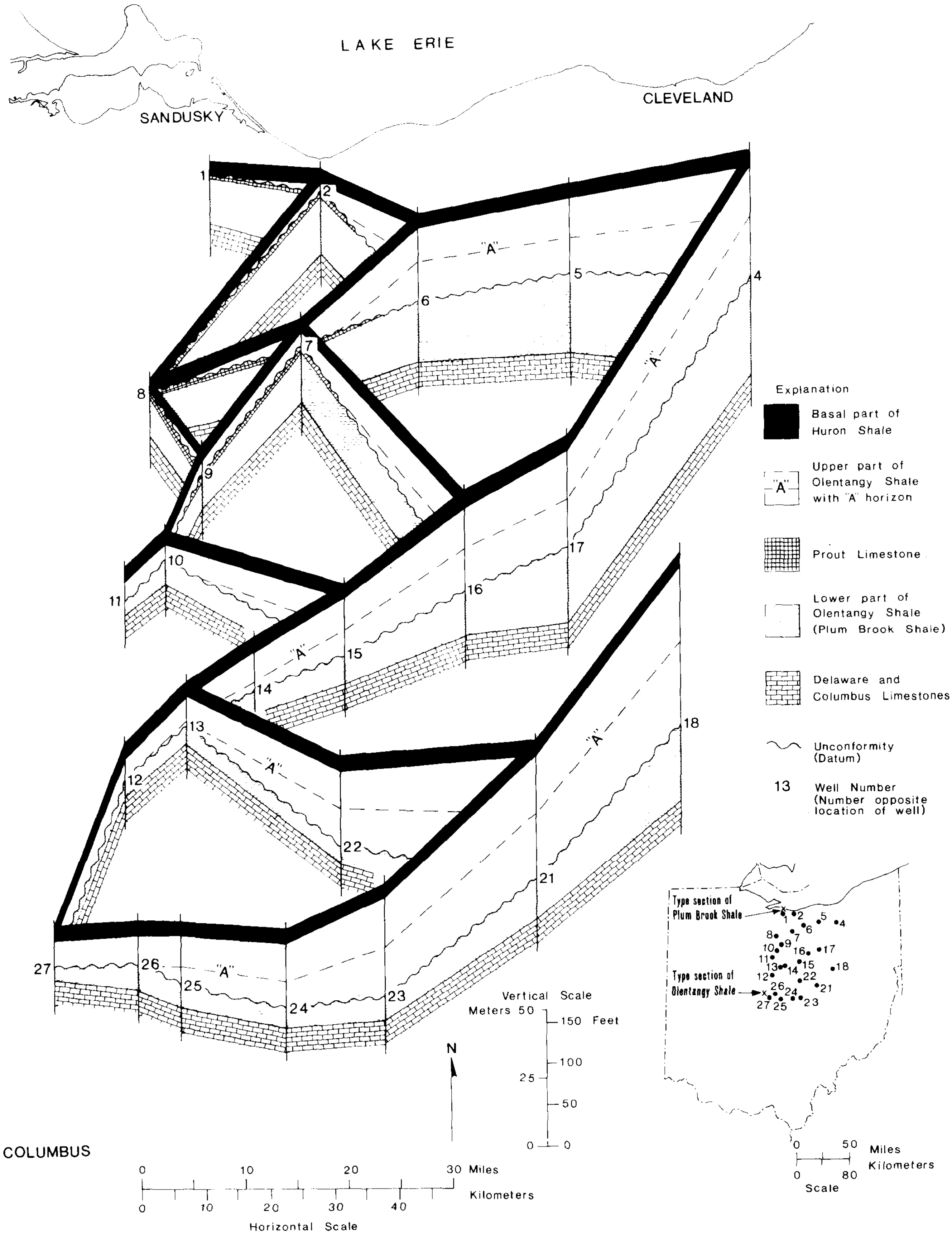


Figure 4.

Fence diagram of Olentangy Shale in north-central Ohio.

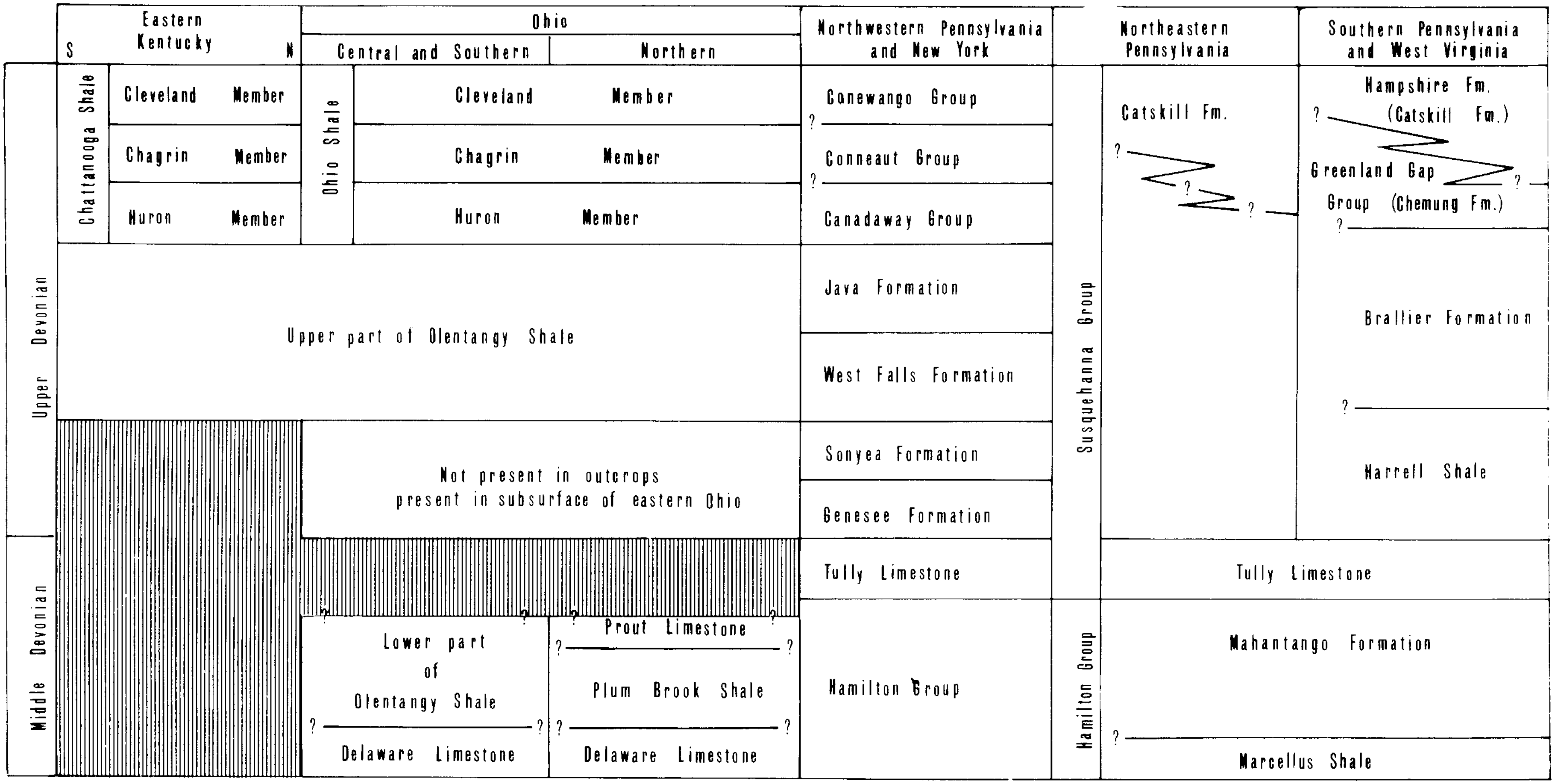


Figure 5.

Chart showing lateral relations between Devonian shales of Ohio and formations to the east and south.

Tillman, 1970, p. 211; Wallace and others, 1977). The lower part of the Olentangy Shale thickens eastward and is between 125 and 200 feet thick at the Ohio-Pennsylvania line. Eastern equivalents are more than 2,000 feet thick in northeastern Pennsylvania (fig. 6). Rickard (1964, 1975) reports between 3,000 and 4,000 feet of Hamilton rocks in southeastern New York. Equivalent rocks are between 300 and 500 feet thick in northern West Virginia.

In the subsurface of eastern Ohio, the lower part of the Olentangy Shale is made up of gray to dark-gray and black shale with thin beds of limestone. A highly radioactive, carbonaceous, black shale is present at its base. The black shale at the base of the lower part of the Olentangy can be traced into the Marcellus Shale. This basal black shale thickens to the east and can be recognized throughout the eastern part of the study area. It thins to the west and doesn't crop out in Ohio. The gray, dark-gray and black shales and limestones above the basal black shale in eastern Ohio can be traced into rocks of the Hamilton Group younger than the Marcellus Shale in southwestern New York. Farther east, these rocks intertongue with red beds of the Catskill lithofacies (fig. 7) (Rickard, 1964, 1975).

The gray shales, black shales, and limestones of the lower part of the Olentangy Shale can be traced into the Marcellus Shale and the Mahantango Formation in Pennsylvania and West Virginia. The Marcellus is made up of noncalcareous grayish-black shale with some carbonate concretions and thin beds of dark-gray limestone. In south-central Pennsylvania, limestone beds, the "Purcell Limestone" of Cate (1963, p. 232), occur in the basal part of the Marcellus Shale, while gray shale and sandstone are present in the middle part. The Marcellus intertongues with the overlying Mahantango Formation (Willard and others, 1939, p. 166-176; Woodward, 1943, p. 311-316). Traced south from northeastern West Virginia, the Marcellus replaces the

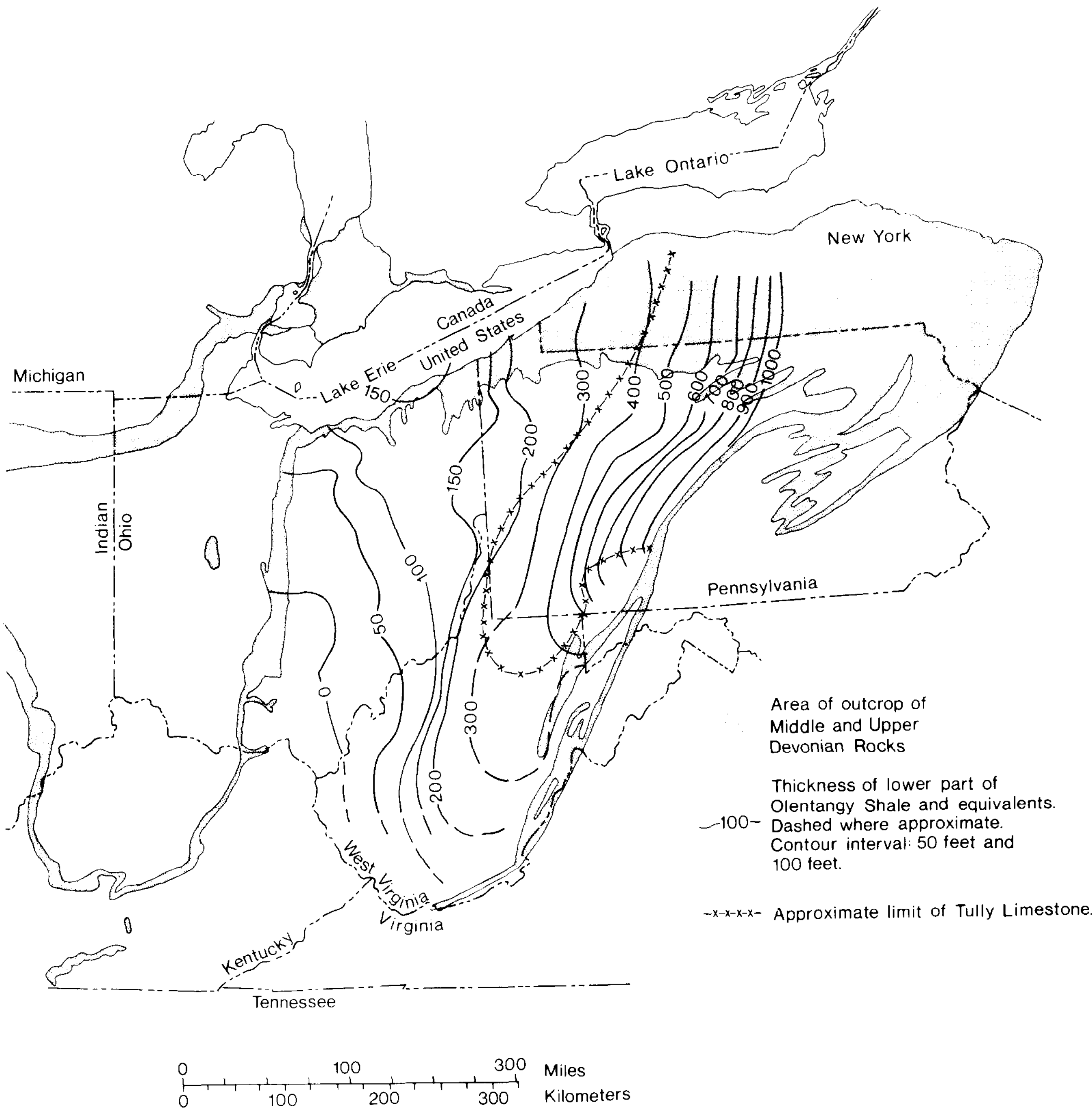


Figure 6.

Isopach map of lower part of Olentangy Shale and equivalents.

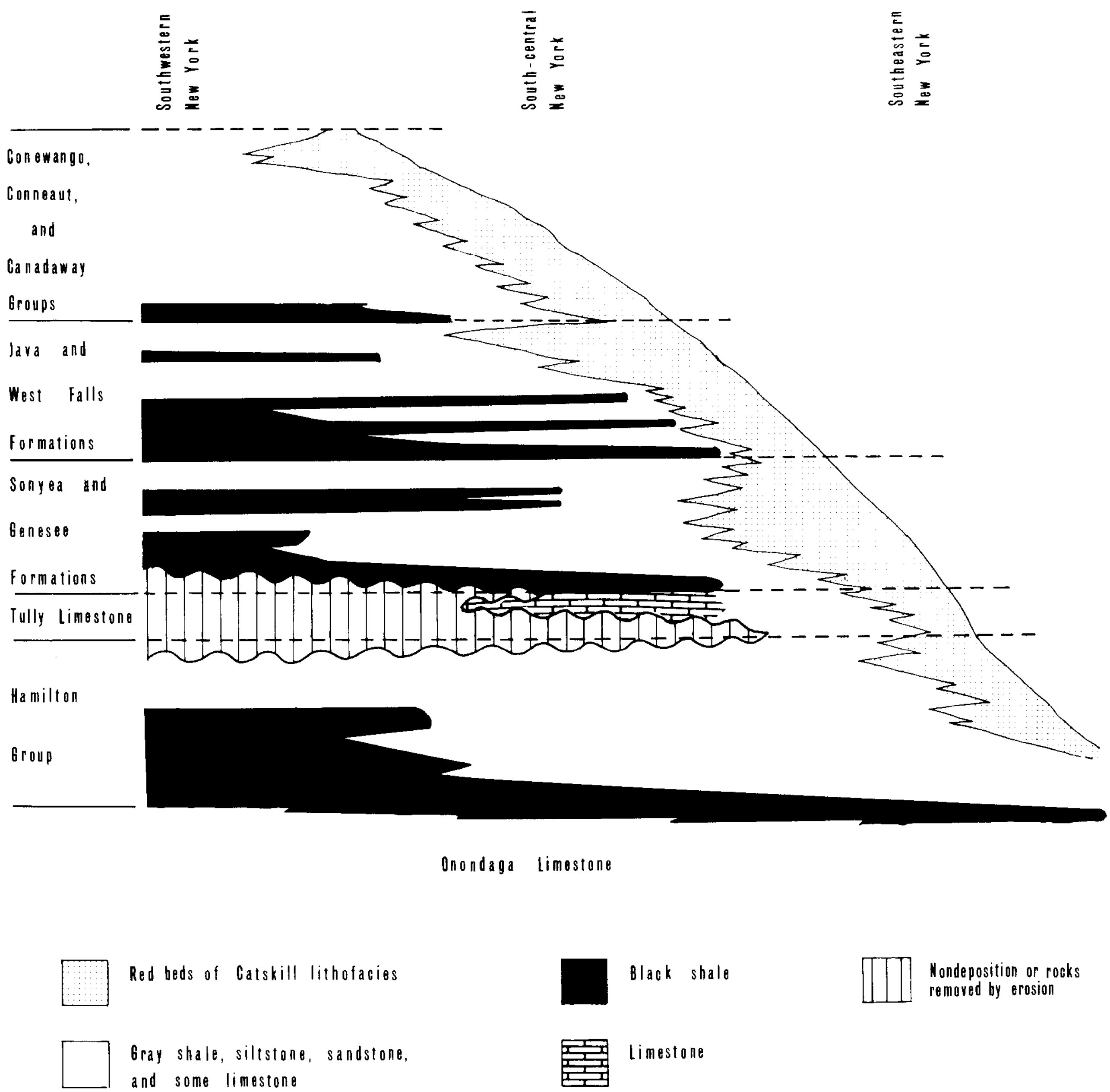


Figure 7.

Relationship of Devonian rocks across southern New York. Drawing based upon correlation charts of Devonian rocks in New York by Rickard (1964, 1975). Drawing is not to scale.

Mahantango by facies change; the latter is absent in southern West Virginia (Dennison and Naegele, 1963, p. 13-16).

The Mahantango Formation consists of interbedded medium- to dark-gray shale, siltstone, sandstone, and some limestone. The contact between the Mahantango Formation and the underlying Marcellus Shale is gradational, and part of the lower Mahantango may be time equivalent to part of the Marcellus. The upper part of the Mahantango interfingers with the Tully Limestone (Ellison, 1965, p. 47). In southeastern Pennsylvania, the Mahantango intertongues with red beds of the Catskill lithofacies (Willard and others, 1939, p. 133-136, 195-200).

A comparison of the isopach map of the lower part of the Olentangy Shale and its equivalents (fig. 6) with isopach maps of the upper part of the Olentangy Shale and the Ohio Shale and their equivalents (figs. 9, 11) shows that, although the lower part of the Olentangy thins southward, the upper part of the Olentangy and the Ohio do not. This suggests that the configuration of the Appalachian basin differed from Middle Devonian to Late Devonian.

Tully Limestone The Tully Limestone was named by Vanuxem (1839, p. 278). It is present in central New York, central and eastern Pennsylvania, and northern West Virginia (fig. 6). However, the limestone called Tully in the subsurface in northern West Virginia may be a limestone older than the Tully of New York (Schwietering and others, 1978). Most writers consider the Tully to be the uppermost unit of the Middle Devonian of New York, but Rickard (1964) shows it as the basal unit of the Upper Devonian. Rickard (1975, p. 9 and correlation chart) briefly discusses the uncertainty about the location of the boundary between the Middle and Upper Devonian and the paleontological evidence that has been advanced to place the Tully in either the Middle or Upper Devonian. Because of the confusion about the determinations of the Middle-Upper Devonian boundary and in interpretating the paleontological data, Rickard (1975) does not place the Tully Limestone in either the Middle of Upper Devonian. Instead he indicates the uncertainty in the stratigraphic position of the Middle-Upper Devonian boundary.

As fossils were not examined in the course of this study, no conclusion is here advanced about the age of the Tully. The results of this study suggest that the Tully is the basal unit of a sequence of rocks formed in a sea that transgressed westward toward the Cincinnati Arch. This conclusion is supported by Huddle (1974, p. 516), who wrote, "The Tully Limestone thins west of Cayuga Lake and disappears near Canadaiqua Lake against the southeast side of a shoal of the Tully sea. Basal units of the overlying Genesee Formation rest disconformably on older and older Hamilton Group units and lap westward over the same shoal."

In south-central New York, the Tully Limestone rests disconformably on the Hamilton Group. However, to the south, in central and south-central Pennsylvania along the Allegheny Front, there is no evidence of a disconformity between the Tully and the underlying Hamilton (Heckel, 1969, p. 12) or the Mahantango Formation, the Hamilton equivalent in south-central Pennsylvania (Ellison, 1963, p. 206-207; 1965, p. 38). The Tully Limestone grades upward into overlying rocks and is overlapped to the west by the Genesee and Sonyea Formations or their equivalents (Plate I, B-B' and Plate II, C-C').

The Tully is not present in Ohio or eastern Kentucky. The "Tully" of drillers in northwestern Pennsylvania and northeastern Ohio appears to be the western extension of the Middle Devonian Tichenor Limestone, as suggested by Austin (1969) and Wright (1973). The Tichenor is present in the upper part of the Hamilton Group in New York. Plate I, Cross Section B-B' shows an interpretation of the relation between the "Tully" of drillers and the Tichenor and Tully of New York.

In central New York and Pennsylvania, the Tully Limestone consists of light- and dark-gray fossiliferous limestone and dark-gray shale (Cooper and Williams, 1935, p. 786-821). To the east, in southeastern New York and northeastern Pennsylvania, the Tully passes first into dark-gray shale and sandstone, and then into red beds of the Catskill lithofacies (fig. 7) (Cooper, 1930, p. 122-123; 1933, p. 540-542).

Genesee and Sonyea Formations The Genesee and Sonyea Formations make up the lower part of the Upper Devonian sequence in New York. These formations, or their equivalents, are present in New York, Pennsylvania, and West Virginia. Equivalents are present in the subsurface of eastern Ohio (fig. 8), but not in the outcrops of Ohio or eastern Kentucky.

The combined thickness of the Genesee and Sonyea Formations increases from a featheredge in eastern Ohio and western West Virginia to more than 900 feet in central New York and central Pennsylvania. The maximum combined thickness of these two formations is not known; Rickard (1975) gives a figure of 2,400 feet in southeastern New York.

In eastern Ohio, the Genesee and Sonyea Formations consist of dark-gray and black shale. Where present, these formations rest unconformably on the lower part of the Olentangy Shale and are overlapped to the west by the upper part of the Olentangy Shale (Plate I, B-B' and Plate II, C-C'). The unconformity at the base of the Genesee-Sonyea in eastern Ohio can be traced into the one that separates Genesee from the Hamilton Group (Middle Devonian)

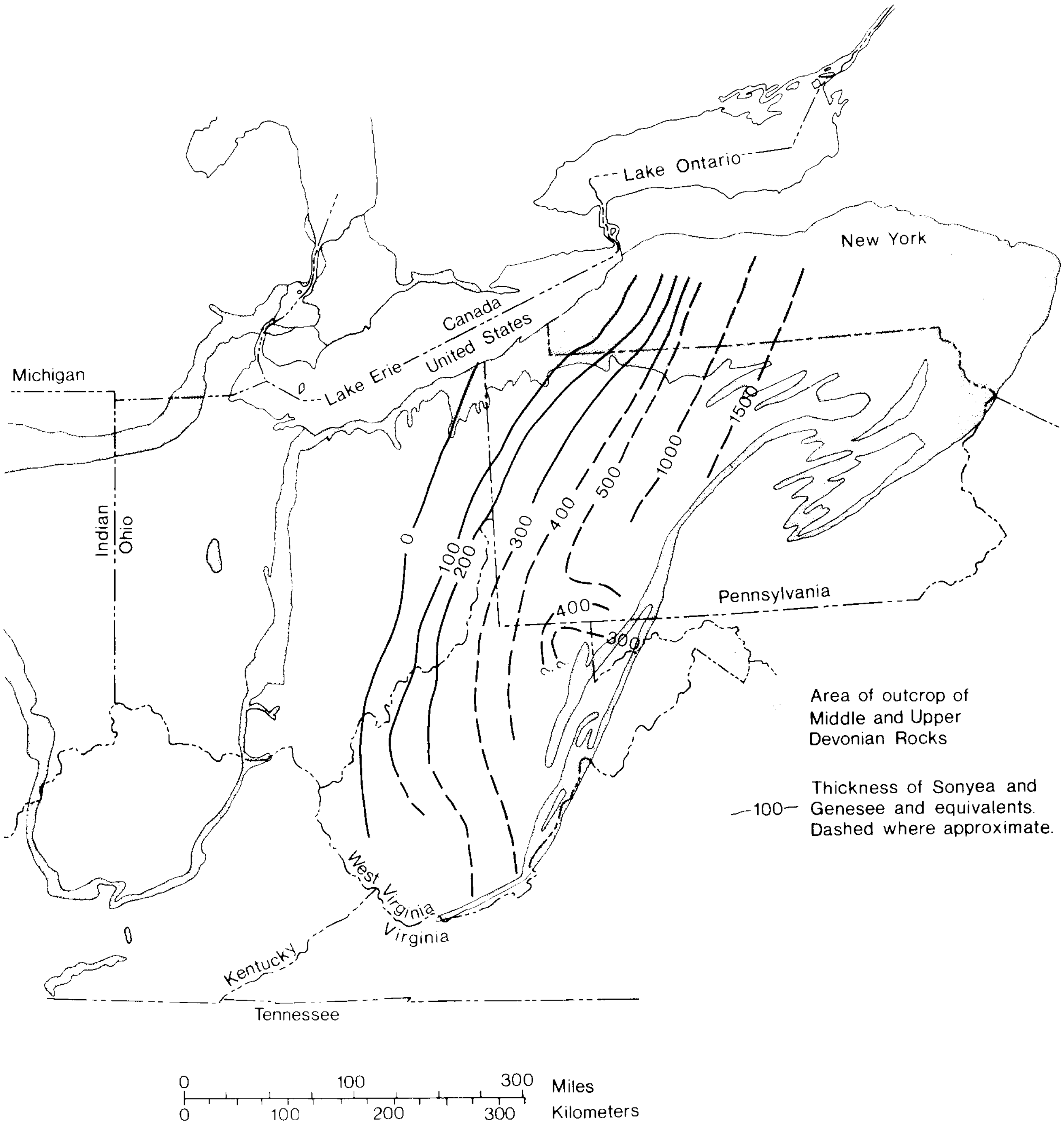


Figure 8.

Isopach map of Genesee and Sonyea Formations and equivalents.

in southwestern New York. Farther east, this same surface separates the Tully Limestone from the Hamilton Group. The Genesee Formation rests conformably on the Tully (Heckel, 1969, p. 2). Rickard (1964, 1975) shows an unconformity between the Genesee and the Tully in south-central New York, but he does not extend it into southeastern New York (fig. 7). The reported unconformity between the Genesee and Tully was not recognized in this study. If present, it may represent a minor regression of the sea.

Traced into southwestern New York, the gray and black shales of the Genesee and Sonyea of eastern Ohio pass into olive-gray, dark-gray, and black shales interbedded with gray argillaceous siltstones and dark-gray limestones (Buehler and Tesmer, 1963, p. 67-74). Farther east, in south-central and southeastern New York, these rocks intertongue with red beds of the Catskill lithofacies (fig. 7) (Sutton, 1963, p. 89-91; Rickard, 1964, 1975).

The Genesee and Sonyea Formations are equivalent to the lower part of the Susquehanna Group in northeastern Pennsylvania (Plate I, B-B'). The Susquehanna Group consists of dark-gray shale, siltstone, and sandstone, which in turn is overlain by red, green, and gray shale, siltstone and sandstone similar to the Catskill lithofacies (Wagner, 1963, p. 68-73).

In West Virginia and southern Pennsylvania, the equivalents of the Genesee and Sonyea Formations are the Harrell Formation and locally the lower part of the Brallier Formation (Plate II, C-C' and D-D'). The Harrell is composed of dark-gray and black shale with thin siltstone beds (Willard and others, 1939, p. 217-219; Woodward, 1943, p. 390-392). The Harrell intertongues with the overlying Brallier Formation and rests conformably on the Mahantango Formation. Where the Tully Limestone is present, the Harrell rests conformably on the Tully.

Upper part of the Olentangy Shale The upper part of the Olentangy Shale is exposed in central and southern Ohio and northeastern Kentucky (Morse and Foerste, 1912, p. 27, 37; Lamborn, 1927, 1929). It is absent in the Bellefontaine Outlier in west-central Ohio and in outcrops in western Erie County, Ohio (fig. 9). The upper part of the Olentangy can be recognized in the subsurface of eastern Ohio, eastern Kentucky, and southwestern West Virginia. Stratigraphic equivalents are present in New York, Pennsylvania, and eastern West Virginia.

From 18 to 26 feet thick at the outcrops in central Ohio (Tillman, 1970, p. 211), the upper part of the Olentangy Shale thickens eastward; equivalents in central New York and central Pennsylvania are more than 2,000 feet thick (fig. 9). In central and southern Ohio and in eastern Kentucky, the upper part of the Olentangy Shale rests unconformably on older rocks (Lamborn, 1927, 1929; Louden, 1965; Tillman, 1969, 1970). Whereas in the subsurface of eastern Ohio the upper part of the Olentangy Shale rests conformably on western equivalents of the Sonyea Formation. The upper part of the Olentangy Shale and its equivalents are overlain conformably by the Ohio Shale and its equivalents.

In the subsurface of eastern Ohio, the upper part of the Olentangy Shale consists of varying proportions of greenish-gray shale, dark-gray shale, black shale, and minor amounts of gray limestone. A highly radioactive dark carbonaceous shale is present at the base of the upper part of the Olentangy Shale in eastern Ohio. This basal radioactive shale thickens to the east, but pinches out to the west and does not crop out in Ohio.

The upper part of the Olentangy Shale can be traced into the West Falls and Java Formations of New York and the upper part of the Susquehanna Group

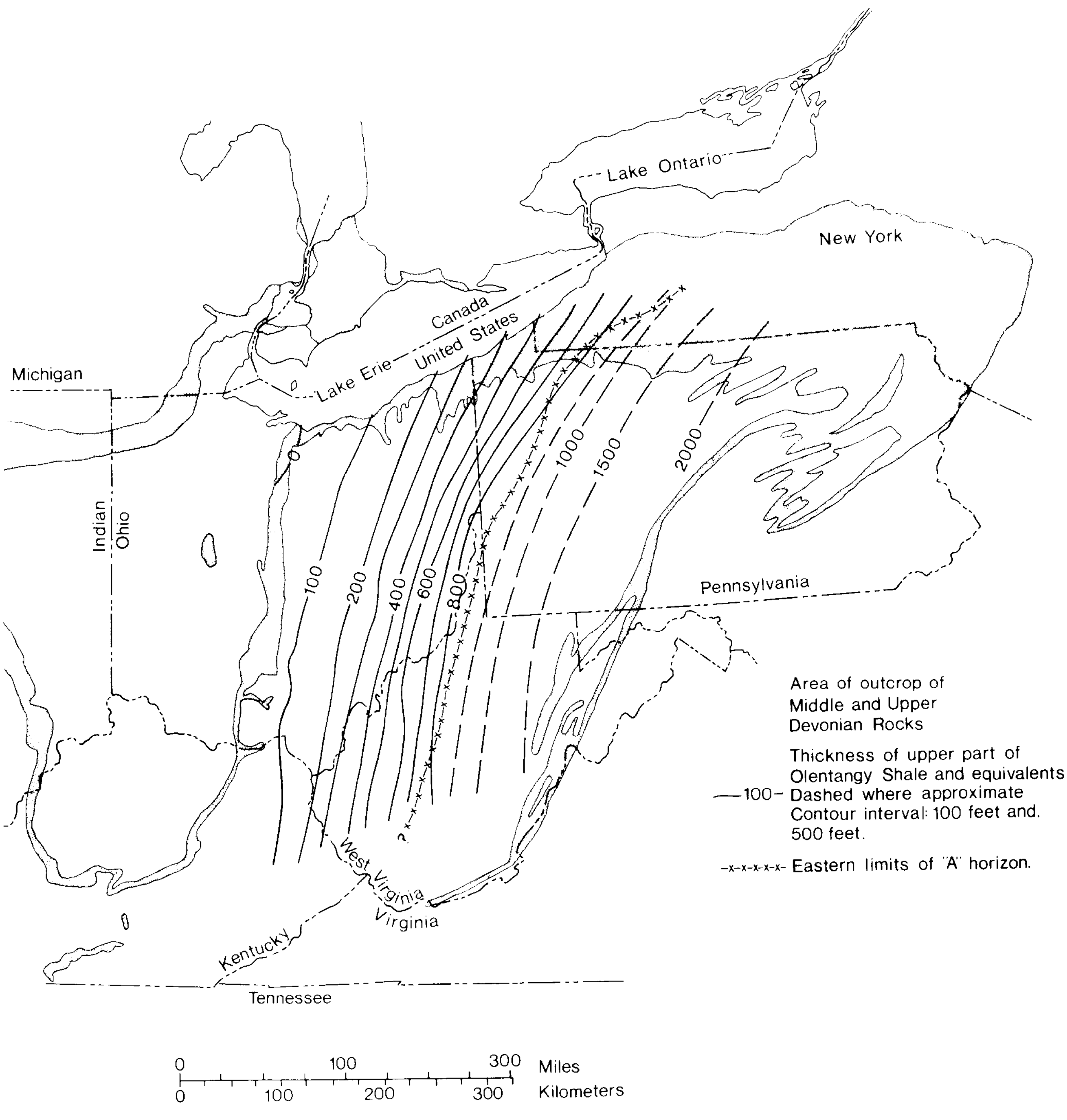


Figure 9.

Isopach map of upper part of Olentangy Shale and equivalents.

of northeastern Pennsylvania (Plate I, B-B'). In southwestern New York, the West Falls and Java Formations consist of interbedded green-gray shale, light-gray shale, and gray-black and black shale, and gray siltstone and sandstone, zones of impure limestone nodules and carbonate septarian concretions (Buehler and Tesmer, 1963, p. 71-86). Farther east, in southeastern New York, these shales, siltstones and sandstones intertongue with red beds of the Catskill lithofacies (fig. 7) (Rickard, 1964, 1975).

In the western part of the area of study, the upper part of the Olentangy Shale can be divided into two parts separated by the "A" horizon, a datum that can be recognized on gamma ray-neutron logs in the western part of the area of study (fig. 2). The "A" horizon is at the base of a moderately high radioactive interval in the upper part of the Olentangy Shale. Only that part of the upper part of the Olentangy above the "A" horizon is exposed in Ohio and eastern Kentucky (Plates I, and II). The "A" horizon is tentatively traced into the base of the Java Formation of New York and is probably the base of the Pipe Creek Member of the Java. Consequently the upper part of the Olentangy Shale present in the western outcrops in Ohio and eastern Kentucky may only be equivalent to the Java Formation of New York. The possible absence of West Falls equivalents in the western outcrops, the westward pinchout of the basal black shale present in the upper part of the Olentangy in the subsurface of eastern Ohio, and the disconformity between the upper and lower parts of the Olentangy Shale, all suggest a westward onlap onto the Cincinnati Arch by the upper part of the Olentangy Shale and its equivalents (fig. 4).

The relationship of the upper part of the Olentangy Shale to the Chattanooga Shale of southern Kentucky and Tennessee is not known. Possibly the upper part of the Olentangy was overlapped by the Ohio-Chattanooga Shale, and equivalents of the upper part of the Olentangy are not present. A relationship similar to that in the Bellefontaine Outlier of west-central Ohio where Columbus Limestone (Middle Devonian) is overlain by the Ohio Shale and the Olentangy Shale is absent.

Traced into West Virginia and southern Pennsylvania, the upper part of the Olentangy Shale passes into the Brallier Formation (Plate II, C-C' and D-D'), which consists of interbedded medium-dark-gray and greenish-gray shale, siltstone, and sandstone. The Brallier intertongues with olive and black shales of the underlying Harrell Formation and with the gray shales and siltstones of the overlying Greenland Gap Group ("Chemung Formation") Willard and others, 1939; Woodward, 1943; Dennison, 1963, 1970).

OHIO SHALE AND EQUIVALENTS

Description and Nomenclature

Andrews (1870, p. 62) applied the name "Ohio slate" to carbonaceous black shale exposed in southern Ohio. Shaler (1877, p. 169) proposed "Ohio shale" for the same rocks, and this latter name has come into general use. In central and southern Ohio, the Ohio Shale consists predominantly of dark-brown carbonaceous silty shale with minor beds of gray and blue-gray mudstone. Discontinuous beds of gray and dark-brown argillaceous limestone, 1 to 2 inches thick, with cone-in-cone structure, are present in the middle and upper parts of the Ohio Shale. Large carbonate septarian concretions occur in the lower part.

The Ohio Shale is composed of silt, clay, carbonaceous matter, and minor amounts of carbonate and pyrite. The silt fraction consists of quartz, feldspar, chlorite, and mica. The clay fraction contains clay minerals (mostly illite, some kaolinite) and clay-sixed quartz grains (Nelson, 1955). Carbonaceous matter is most abundant in dark-gray to brown-black shale and least abundant in light- and medium-gray shale. Most of the carbonaceous material consists of finely disseminated masses of silt- and clay-sized particles of plant matter. The carbonate occurs in concretions and thin discontinous limestone beds. The pyrite is present as finely disseminated particles, irregularly shaped nodules, small concretions, and replacement of *Tasmanites* spore cases. In the last named form, the pyrite occurs as flattened discs and spheres as much as 0.5 mm in diameter. The shale is thinly laminated, and on unweathered surfaces is hard and massive. On weathered surfaces prominent joints develop and the shale becomes fissile, some of the darker layers commonly weathering to paper-thin "leaves." The darker shales are uraniferous. Oil and gas are produced from the shale Hoover, 1960, p. 62-67; Janssens and de Witt, 1976).

Fossils belonging to the following groups of animals and plants have been reported from the Ohio Shale: conodonts, radiolaria (Foreman, 1959, 1963), inarticulate and articulate brachiopods, crinoids (Wells, 1941), fish, spores, algae, logs of land plants (Wells, 1947), and trace fossils (worm markings?). If it is assumed that the logs of land plants were washed into an inland sea from surrounding land masses, then the fossils present in the Ohio Shale indicate a normal marine or brackish-water environment of deposition.

In much of northern Ohio, the stratigraphic interval of the Ohio Shale is divided into three members, in ascending order, the Huron Member, the Chagrin Member, and the Cleveland Member (fig. 5). This subdivision of the Ohio Shale is generally restricted to northern Ohio, although a similar subdivision can be recognized in central and southern Ohio (Lamborn, 1934, p. 357-358) and in the subsurface of eastern Ohio and eastern Kentucky (Provo, 1977). Provo and others (1977) named a new unit in the Ohio Shale, the Three Lick Bed. They recognized this unit in eastern Kentucky, southern Ohio, and southwestern West Virginia. The Three Lick Bed consists of a zone of interbedded dark-greenish-gray and brownish-black shale that underlies the uppermost massive unit of dark-gray to brownish-black shale of the Ohio Shale. The Three Lick Bed appears to represent a southern tongue of the uppermost part of the Chagrin Member.

<u>Huron Member</u> Newberry (1870, p. 18) applied the name "Huron shale" to

shales present along the Huron River in north-central Ohio. These shales are dark-gray to black in color with minor amounts of blue-gray to gray shale. Large septarian concretions are present in the Huron, but limestones with cone-in-cone structures are absent. In north-central Ohio, the Huron rests disconformably on the Prout Limestone (Middle Devonian), and intertongues with the overlying Chagrin Member. In eastern, central, and southern Ohio, the Huron Member rests conformably on the upper part of the Olentangy Shale.

Lamborn (1934, p. 358), in describing the subsurface section of eastern Ohio, wrote "[above] the base of the Ohio shale there is a bed of black or brown shale which is generally known to the driller as Cinnamon. Over large areas in eastern Ohio the Cinnamon is divided into two parts by a thin bed of blue gray shale. . . The black Ohio shale of outcrops in central and southern Ohio is believed to represent the western continuation of the Cinnamon shale of the driller." Examination of gamma ray-neutron logs during the course of this study indicates that the two "Cinnamon" shales are not eastern equivalents of the entire Ohio Shale of the western outcrops, but that they that they are eastern tongues of the lower part of the Ohio Shale (Huron Member) (fig. 2, fig. 10c).

<u>Chagrin Member</u> Prosser (1930a, p. 533-534) first used the name "Chagrin shale" to replace the name "Erie shale," proposed by Newberry (1870, p. 21), because that name was preoccupied. The Chagrin, typically exposed along the Chagrin River east of Cleveland, is made up of blue and gray mudstone and claystone interbedded with discontinuous beds of gray siltstone up to 2 inches thick. Near the Ohio-Pennsylvania line, thick beds of siltstone are present in the upper part of the Chagrin Member. Where the Cleveland Member and the Cussewago Sandstone (a Mississippian sandstone lying

between the Chagrin Member and the Mississippian Bedford Shale in parts of northern Ohio and northwestern Pennsylvania) are absent, it is difficult to separate the Chagrin from the overlying Bedford Shale. The Chagrin thins to the west and intertongues with the overlying Cleveland Member and the underlying Huron Member (fig. 10c). Because of the intertonguing of the Chagrin with the Cleveland and the Huron it is difficult, if not impossible, to delineate definite contacts between the Cleveland and the Chagrin and between the Chagrin and the Huron.

Cleveland Member The Cleveland Member was named by Newberry (1870, p. 19, 21). The Cleveland Member is a black shale that locally contains beds of gray shale and siltstone and thin cone-in-cone limestone. The gray shale and siltstone are most common in the lower part of the Cleveland Member. Irregularly shaped concretions are present in the Cleveland; however, no large septarian concretions are found in it (Hoover, 1960, p. 23). The unit is 20 to 100 feet thick at Cleveland, the type area. It thins eastward and is not present in easternmost Ohio or in states to the east. The Cleveland Member intertongues with the underlying Chagrin Member (Pepper and others, 1954, p. 16) and is overlain with apparent conformity by the Bedford Shale. Pepper and others (1954, p. 15) describe the contact between the Cleveland Member and the overlying Bedford Shale as ". . . generally well defined from Berea, Ohio to Irvine, Ky. In some places a transition zone ranging from a few inches to 4.2 feet in thickness separates the black shale of Devonian age from the succeeding red or gray shales of the Bedford." In the subsurface, Lewis and Schwietering (1971) and Wallace and others (1977) were able to trace the Cleveland Member south from Cleveland through central and southern Ohio into northeastern Kentucky.

Cushing (1912, p. 582-583) applied the name "Olmsted shale" to "15 to 20 feet of blackish soft shale" which underlies the Cleveland, overlies the Chagrin, and is typically exposed along Rocky River west of Cleveland. Cushing considered the Olmsted to be a separate formation, which wedged out eastward between the Cleveland and Chagrin shales, and he did not recognize it east of Cleveland. He noted a westward thickening of the Olmsted and the concurrent thinning of the Chagrin, and suggested that part of the Huron Member exposed along the Huron River and much of the Ohio Shale at Columbus is Olmsted.

Pepper and others (1954, p. 16) described the lower part of the Cleveland Member, Cushing's Olmsted Member, as "black shale, many beds of bluish-gray or gray shale that range in thickness from an inch to several feet; some thin gray to brown siltstone; many small nodules and lumps of pyrite; and several thin siliceous limestones that are characterized by cone-in-cone structure." They considered the Olmsted to be part of the Cleveland Member and to represent intertonguing of black shale of the Ohio Shale with gray shale of the Chagrin.

Lewis and Schwietering (1971) could not consistently separate the Olmsted from the Cleveland on gamma ray-neutron logs or in well cuttings; consequently we considered the Olmsted to be part of the Cleveland. In the subsurface we found a belt of thick Cleveland, as much as 110 feet thick, a few miles east of the outcrop, which extends south from north-central Ohio through the central part of the state and passes into Kentucky a few miles east of Portsmouth, Ohio. The Cleveland thins eastward and westward from this thick belt. These data show that the Cleveland does not thicken to the west and south as suggested by Cushing (1912).

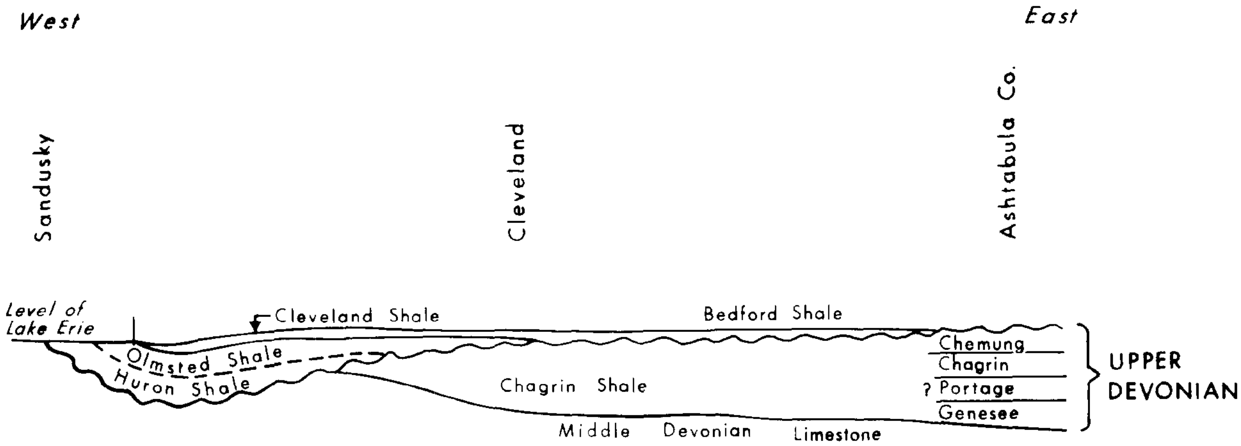


Figure A. Modified from Ulrich, 1912, p. 166, fig, 1.

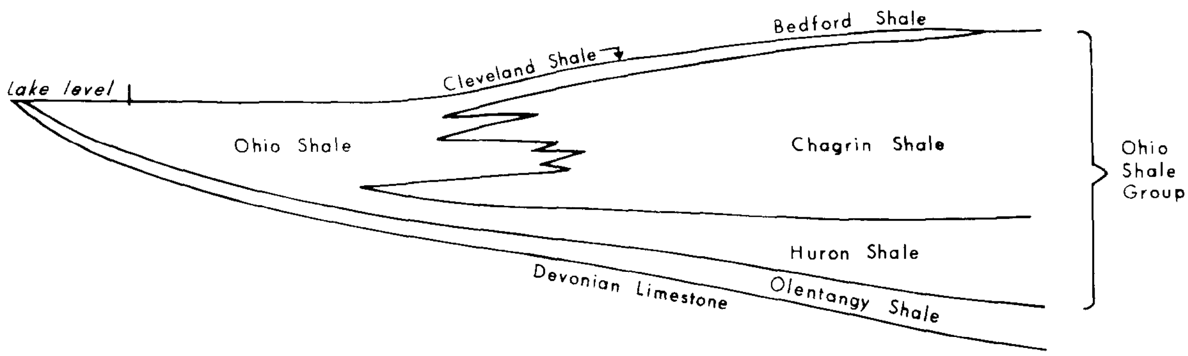


Figure B. Modified from Kindle, 1912, p. 204, fig.3.

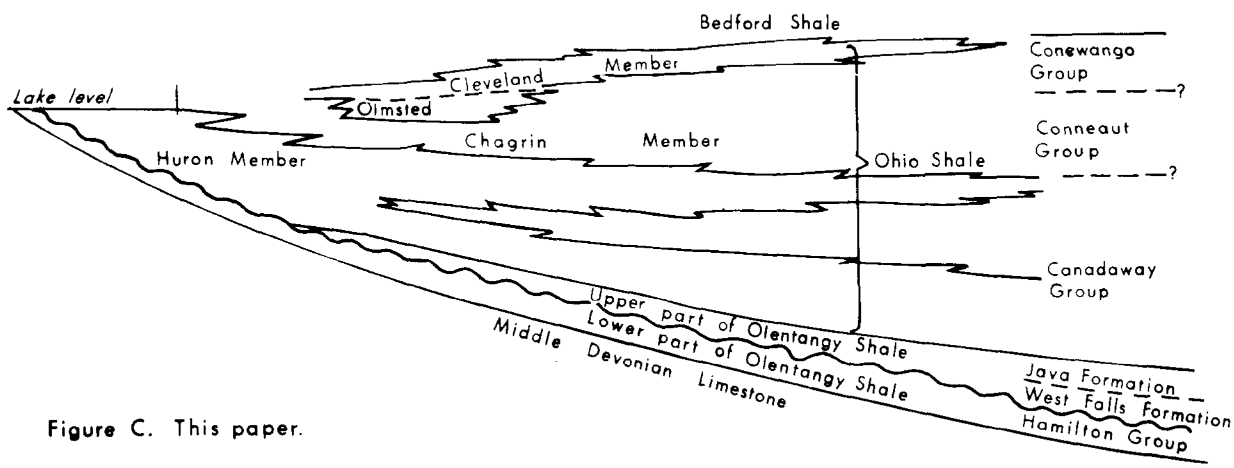


Figure C. This paper.

Figure 10.
Three concepts of the relationship of the Chagrin Member to the Cleveland and Huron Members of the Ohio Shale. Drawings are not to scale.

Age

In 1912, Ulrich suggested that the Huron, Olmsted, and Cleveland shales are all part of a continuous rock mass (Ohio Shale) which diconformably overlies the Chagrin Shale (fig. 10a). He considered the Chagrin to be the western equivalent of the Chemung and possibly of the Portage and Genesee, all Upper Devonian rocks, of New York. He based his conclusion in part on the eastward thinning of the Cleveland Shale, the westward thinning of the Chagrin Shale (Genesee, Portage, Chagrin, and Chemung of fig. 10a), and in part on the difference between fossils in the Huron and Cleveland to those in the Chagrin.

Kindle (1912) disagreed with Ulrich's conclusions. He considered the Huron, Chagrin, and Cleveland to be formations and members of the Ohio Shale Group, and all to be Late Devonian in age (fig. 10b). He presented evidence that the Huron and Cleveland intertongue with the Chagrin, and that the Chagrin passes westward into dark shales similar to the Huron and Cleveland. He thought the difference between the fossils of the Huron and Cleveland and those of the Chagrin could be attributed to different environments of deposition, the Chagrin representing nearshore shallow-water environment, the Huron and Cleveland an offshore deeper-water environment.

Caster (1934) recognized two magnafacies in northern Ohio, the Cleveland Magnafacies (black shale) and the Chagrin Magnafacies (blue-gray shale, siltstone, and fine sandstone). He pictured the light-colored fine clastics of the Chagrin Magnafacies (Chagrin Member) as a wedge lying between and intertonguing with black shales of the Cleveland Magnafacies (Huron and Cleveland Members) to the west. He considered the Cleveland and Chagrin Members to be Late Devonian in age, equivalent to the Riceville Shale and the

Venango Group in western Pennsylvania.

Hass (1947) divided the Ohio Shale into two faunal zones on the basis of conodonts. The lower zone, of Late Devonian age, consists of the Huron and Chagrin in northern Ohio and the lower part of the Ohio Shale undifferentiated in central and southern Ohio. The upper zone, latest Devonian or Mississippian in age, consists of the Cleveland and Olmsted in northern Ohio and the upper part of the Ohio Shale undifferentiated in central and southern Ohio. Because of the great difference between the faunas of the two zones, Hass suggested that there may be a hiatus between them.

Pepper and others (1954, p. 14-17) pictured and described the Chagrin as a wedge of gray shale and siltstone intertonguing with, and pinching out westward between, the black shale of the Cleveland and Huron, which merge westward to form the Ohio Shale. The upper beds of the Chagrin are considered to be equivalent to the Riceville Shale of western Pennsylvania. Pepper and others (1954) considered the Ohio Shale to be Upper Devonian, and placed the Devonian-Mississippian boundary at the contact of the Cleveland Member and the Bedford Shale (Chagrin-Bedford contact where the Cleveland is absent).

Correlation

The Ohio Shale is recognized in Ohio, eastern Kentucky, and southwestern West Virginia. To the east, the Ohio Shale intertongues with rocks of different lithologies and names. The thickness of the Ohio Shale and its equivalents are shown in figure 11. Along the western outcrop belt, the thickness of the Ohio Shale ranges from about 150 feet in east-central

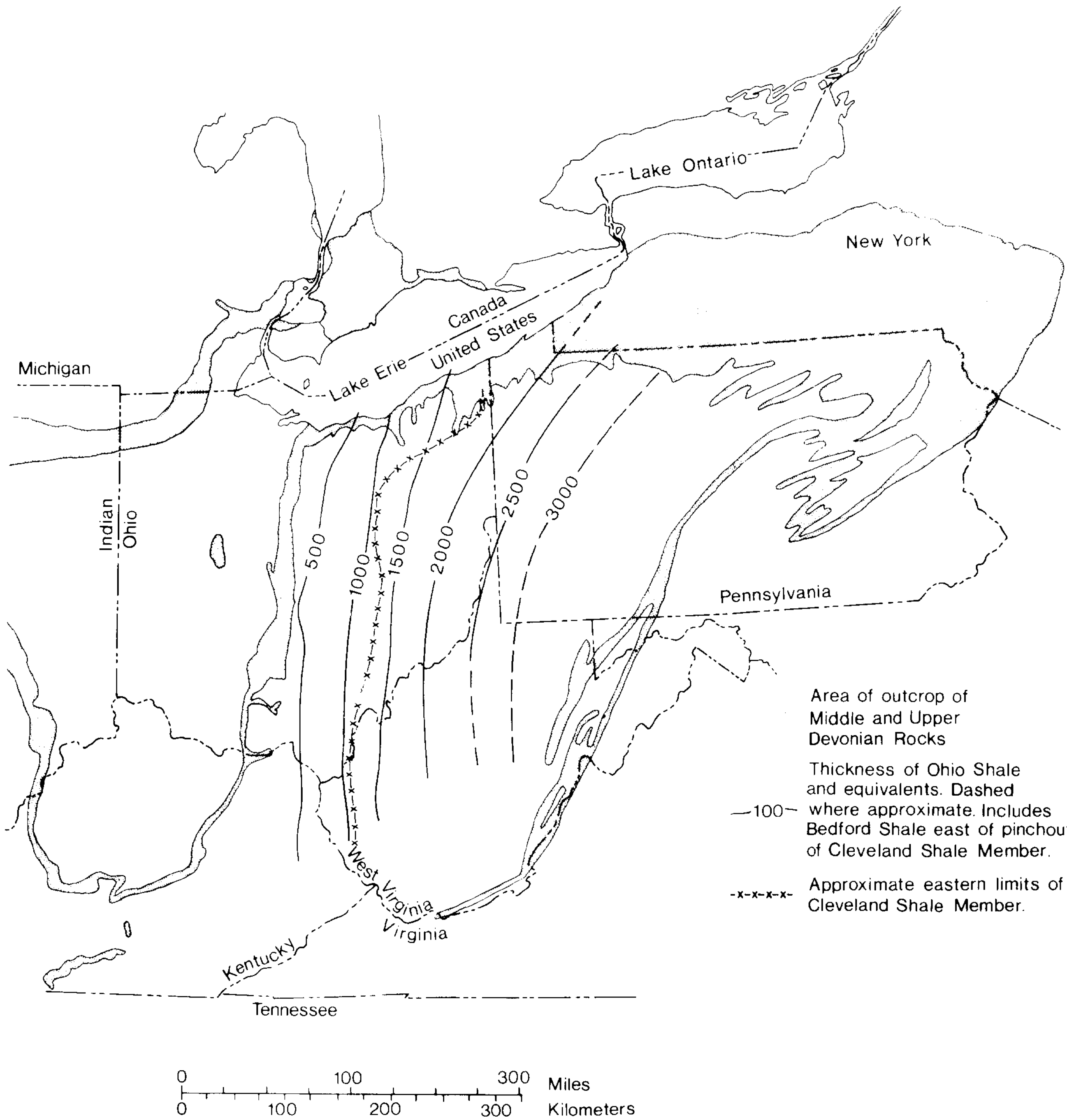


Figure 11.

Isopach map of Ohio Shale and equivalents.

Kentucky to about 400 feet in central and northern Ohio. In the Bellefontaine Outlier approximately 190 feet of Ohio Shale is exposed. Only the lower and middle parts are present, the upper part having been removed by erosion. In the outlier, the shale rests disconformably on the Columbus Limestone (Middle Devonian). The Olentangy Shale and the underlying Delaware Limestone are absent. In north-central Ohio, the Ohio Shale rests disconformably on the Prout Limestone; here the upper part of the Olentangy is absent. In the eastern and southern parts of Ohio, the Ohio Shale rests conformably on the Olentnagy Shale. The Ohio Shale is conformably overlain by the Bedford Shale (Mississippian).

The Ohio Shale thickens eastward, and in eastern Ohio is 2,000 to 2,500 feet thick (fig. 11). Stratigraphic equivalents in central Pennsylvania are more than 3,000 feet thick. The thickness farther east is not known because of uncertainties in determining the top and bottom of the unit. On figure 11, east of the pinchout of the Cleveland Member, the thickness of the Bedford Shale is included with that of the Ohio Shale. This inclusion is not thought to greatly displace the position of the isopach lines, because the contour interval is more than twice the maximum thickness of the Bedford, and the Bedford is thought to thin eastward (Pepper and others, 1954, p. 23).

East of the western outcrop belt, the Cleveland Member intertongues with, and wedges out between, the Chagrin Member and the Bedford Shale (Plate II, C-C' and D-D'). The Chagrin Member thickens eastward. In the subsurface of eastern Ohio, the Huron Member consists of upper and lower radioactive carbonaceous dark shale units separated by lighter colored shale with lower radioactivity (fig. 2). The dark shales correspond to the two "Cinnamon" shales in eastern Ohio described by Lamborn (1934, p. 357-358) and Brwon Shale Zone II and Zone III in southwestern West Virginia described by

Martin and Nuckols (1976). To the east, the upper dark shale grades into medium- and dark-gray shale and gray siltstones in eastern Ohio; the lower dark shale continues eastward into West Virginia and western Pennsylvania, where it intertongues with medium- and dark-gray shale and gray siltstone.

In northwestern Pennsylvania and New York, the Chagrin Member has been traced in the subsurface into the Conewango and Conneaut Groups, and possibly into the uppermost part of the Canadaway Group (Plate I, B-B'). The basal part of the Huron Member passes into the Dunkirk Shale Member of the Perrysburg Formation of Pepper and de Witt (1951). The Perrysburg is the basal formation of the Canadaway Group of New York. The Dunkirk is a carbonaceous black shale with some intercalated medium-gray shale and contains septarian concretions. This shale thins to the east and is not recognized east of Steuben County, south-central New York (Pepper and de Witt, 1951).

The Conewango and Conneaut Groups are made up of interbedded gray shale, siltstone, and sandstone with some conglomerate and red beds in the upper part. The Canadaway Group consists of interbedded gray, brown, and black shale and siltstone. Carbonate septarian concretions are present (Tesmer, 1963, p. 14-44). On correlation charts of Devonian rocks of New York, Rickard (1964, 1975) shows the above groups intertonguing with red and green shales and sandstones of the Catskill lithofacies (fig. 7). The lower gray shales, siltstones, and sandstones extend farther east than the upper ones.

In the subsurface, the Ohio Shale has been traced eastward from Ohio into central Pennsylvania and West Virginia where it passes into the Greenland Gap Group ("Chemung Formation") and possibly into the upper part of the Brallier Formation (Plate II, C-C' and D-D'). These units are composed of rocks similar to those in the Canadaway, Conneaut, and Conewango

Groups. Traced farther east, the Greenland Gap intertongues with red beds of the Catskill lithofacies (Dennison and Naegele, 1963, p. 22-23). In central and southern Pennsylvania and West Virginia, as in New York and northern Pennsylvania, the lower gray shales, siltstones, and sandstones extend farther east than the upper ones (Willard and others, 1939; Woodward, 1943; Dennison, 1970).

The Huron, Chagrin, and Cleveland Members of the Ohio Shale can be traced into northeastern Kentucky and southwestern West Virginia (Plate I, A-A'). In east-central Kentucky, the Chagrin is absent and the Cleveland merges with the Huron and forms the lower part of the Chattanooga Shale. The Three Lick Bed in eastern Kentucky described by Provo and others (1977) is a southern extension of the uppermost part of the Chagrin Shale of Ohio.

Morse and Foerste (1909) described sections of the Ohio Shale and the overlying Bedford Shale, Berea Sandstone, and Sunbury Shale in southern Ohio and eastern Kentucky. The Sunbury Shale is a black shale similar to the Ohio. Morse and Foerste noted the southward thinning of all these formations, and the absence of the Bedford and Berea south of Estill County, east-central Kentucky. Because the rate of thinning of the Bedford and Berea appeared to be greater than that of the Sunbury and the Ohio, Morse and Foerste came to the conclusion that the Bedford and Berea pinch out southward between the black shales and that in Estill County the Sunbury and the Ohio join to form the Chattanooga Shale. This interpretation has been followed by later workers.

GEOLOGIC HISTORY

Oliver and others (1967, 1971) described the Devonian rocks in the Appalachian basin and summarized existing knowledge of these rocks. On cross sections they show the western black shales (Ohio-Chattanooga) to be Upper Devonian and physically continuous with black shales in the Middle Devonian and the lower Upper Devonian in the east. Their interpretation suggests that only one major transgression of the sea occurred in the Appalachian basin during the Middle and Late Devonian, and that the distribution of black shale in the section represents a westward migration of the black-shale facies as the sea trangressed westward from the basin onto the Cincinnati Arch. The following discussion suggests that these conclusions are incorrect.

During the Middle and Late Devonian, the Catskill Delta built westward into the Appalachian basin. Friedman and Johnson (1966) described this delta as the type example of a tectonic delta complex, which they define as "a delta complex built into a marine basin contiguous to an active mountain front and dominated by orogenic sediments." The Catskill Delta forms a clastic wedge that extends from the Hudson River in eastern New York west to Lake Erie, and from central New York southward to northern Virginia. Sediments making up this clastic wedge range in thickness from 2,000 or 3,000 feet in the west to more than 10,000 feet in eastern Pennsylvania and New York.

Associated with the westward building of the Catskill Delta were two major westward transgressions of the sea onto the Cincinnati Arch. The regression that separated them is represented by the unconformity at the top of the lower part of the Olentangy Shale in the west and the top of the Hamilton Group in New York. The lower part of the Olentangy and the Hamilton represent the upper part of the sequence of rocks formed during the Middle Devonian transgression. The Devonian rocks above the unconformity represent the lower part of the sequence formed during the Late Devonian and Mississippian transgression.

Sloss and others (1949, p. 110-121) applied the name Kaskaskia Sequence to Devonian and Mississippian rocks resting on an erosion surface cut on Middle Devonian and older rocks and lying beneath Chesterian (Upper Mississippian) clastics. Sloss later (1963, p. 99-102) redefined the Kaskaskia Sequence to include the Chesterian clastics. Johnson (1971, p. 3282-3286, 3291-3292) correlated the Kaskaskia Sequence with the Catskill Delta and the Acadian Orogeny. As a result of his studies, Johnson came to the conclusion that times of transgression of epicontinental seas are times of orogeny along the continental margins and that times of regression of epicontinental seas are times of geosynclinal (orogenic) quiescence.

Wheeler (1963a, 1963b) divided Sloss's Kaskaskia Sequence into two sequences, a lower Piankasha Sequence and an upper Tamaroa Sequence, separated by the Acadian Discontinuity. Wheeler placed the discontinuity (regional unconformity) at the base of the Ohio and Chattanooga Shales in the west and at the base of the Canadaway Group in the east. In my subsurface studies I found a major unconformity between the Middle and Upper Devonian section in the western and northern parts of the Appalachian basin. However, the break is located at the top of the lower part of the Olentangy Shale and the Hamilton Group, not at the stratigraphic position suggested by Wheeler. If my conclusions are correct, then it would appear to be necessary to redefine Wheeler's Tamaroa Sequence to include not only the Ohio Shale and its equivalents, but also the upper part of the Olentangy Shale, the Tully Limestone, and the Genesee, Sonyea, West Falls, and Java Formations. Wheeler's Pinkasha Sequence would then include the Hamilton Group, the lower part of the Olentangy Shale, the Onondaga Limestone and its equivalents, and the Oriskany Sandstone and its equivalents.

Thus it appears that in the western and northern parts of the Appalachian basin the Middle and Upper Devonian rocks can be divided into two sequences, each sequence representing a transgression of an epicontinental sea. The two transgressions were associated with two major orogenic pulses during the Acadian Orogeny. The unconformity separating the two sequences represents a regression of the earlier epicontinental sea and a time of quiescence during the Acadian Orogeny.

The major Middle and Late Devonian transgressions during which the above sequences were formed in the Appalachian basin proceeded in pulses. Pepper and de Witt (1951) described cycles produced during the Late Devonian eastward transgressions and westward regressions of the sea on the Catskill Delta in New York. A cycle consists of black mud at the base, followed by brown and dark-gray mud in the middle part, and silty mud, silt, and fine sand at the top. The black muds of the major cycles are the black shales on figure 7. McCave (1969a, 1969b) and Johnson and Friedman (1969) described eastward transgressions of the sea on the Catskill Delta during Late Middle Devonian. The Middle Devonian transgressions are represented by marine limestones (Tully, Tichenor, and Portland Point) and nearshore and shoreline deposits of gray shale, siltstone, sandstone, and red and green shale and siltstone in the east.

The relation between the westward transgression of epicontinental seas onto the Cincinnati Arch and the eastward transgression of the seas onto the Catskill Delta described by Pepper and de Witt (1951), McCave (1969a, 1969b), and Johnson and Friedman (1969) is best explained if the transgressions proceeded in pulses and were partly the result of rises in sea level. If the transgressions were in part the result of rises in sea level, then the sea should have advanced simultaneously on all the bordering lands of the Appalachian basin. In the eastern areas, the delta front would retreat and advance. Because of the large quantity of sediments coming from the eastern highlands, eventually the net result would be a westward advance of the delta front (fig. 7). In the western area, a high rise in sea level would cover the Cincinnati Arch and join the seas present in the Appalachian, Michigan, and Illinois basins.

That the Cincinnati Arch was covered during parts of both major transgressions during the Devonian is indicated by the presence in the Bellefontaine Outlier, near the crest of the Cincinnati Arch, of the Columbus Limestone (Middle Devonian), part of the Piankasha Sequence of Wheeler, and the Ohio Shale, part of the Tamaroa Sequence of Wheeler.

Black shales are present in the Upper Devonian strata of the Illinois and Michigan basins. The presence of black Ohio Shale in the Bellefontaine Outlier suggests that the black shales of Indiana (New Albany), Michigan (Antrim), and Ohio were part of a continuous sheet.

ACKNOWLEDGMENTS

This paper is based upon my dissertation written while a student at The Ohio State University. I wish to thank R.L. Bates of The Ohio State University, Department of Geology and Mineralogy, who acted as adviser and supervised the preparation of the dissertation; J.M. Schopf and Wallace de Witt, Jr. of the United States Geological Survey for their very helpful critical comments; the staff of the Ohio Division of Geological Survey who released data that helped in this study, provided space to examine well cuttings, and reviewed the manuscript; the Appalachian Log Service, Pittsburgh, Pennsylvania, and Columbus, Ohio who made available gamma ray-neutron logs used in this investigation; Paul W. Queen, West Virginia Geological and Economic Survey for help in drafting illustrations; and Phyllis Bialobok, West Virginia Geological and Economic Survey for help in typing the manuscript.

I am indebted to the Department of Geology and Mineralogy of The Ohio State University for financial aid from the Bownocker Fund and Friends of Orton Hall Fund, which helped defray the cost of my studies, field work, and the preparation of my dissertation.

Published by permission of the Director and State Geologist, West Virginia Geological and Economic Survey. The revision of the dissertation, drafting and typing funded under U.S. DOE contract no. EY-76-C-05-5199.

APPENDIX A

Wells used in constructing cross sections and fence diagrams

Well no.	Permit no.	Well name and number	Operator	Location
1	?	Prout Station core	Ohio Geological Survey	Lot Q-3, Oxford Twp., Erie Co., Ohio
2	P-9	Willis no. 1	Floto & Mammoth	Lot 9, 2nd Qtr., Berlin Twp., Erie Co., Ohio
3	P-191	Rhoa no. 1	Horizon Oil Co.	Lot 30, 3rd Qtr., Trumbull Twp., Ashtabula Co., Ohio
4	P-1214	Hier no. 3-A	Wiser Oil Co.	Lot 70, Hinckley Twp., Medina Co., Ohio
5	P-859	Maurer Investment Co. no. 1	Great Basin Petroleum Co.	Lot 56, Grafton Twp., Lorain Co., Ohio
6	P-854	Gregg no. 1	Midland Exploration Co.	Tract 8, Lot 32, Brighton Twp., Lorain Co., Ohio
7	P-43	Clayton-Crecelius no. 1	Kin Ark Oil Co.	Lot 31, 3rd Qtr., Fitchville Twp., Huron Co., Ohio
8	P-30	Niederweier no. 1	Reliance Oil Co.	Lot 5, 3rd Qtr., Richmond Twp., Huron Co., Ohio
9	P-271	Champion no. 1	Hallion Petroleum Co.	Sec. 25, Plymouth Twp., Richland Co., Ohio

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
10	P-8	Krichbaum no. 1	Sun Oil Co.	Sec. 33, Vernon Twp., Crawford Co., Ohio
11	P-30	Ricker no. 1	Sun Oil Co.	Sec. 26, Polk Twp., Crawford Co., Ohio
12	P-2274	Frazier no. 1	Mansfield Oil and Development	Sec. 14, Gilead Twp., Morrow Co., Ohio
13	P-2421	Higgins no. 1	General Oil Co. of Ohio Inc.	Sec. 23, Congress Twp., Morrow Co., Ohio
14	P-323	Augustine no. 1	Hadson Ohio Oil Co.	Sec. 34, Troy Twp., Richland Co., Ohio
15	P-415	Sauder no. 1	Olympic Petroleum Co.	Monroe Twp., Richland Co., Ohio
16	P-2355	Allen no. 1	Kingwood Oil Co.	Sec. 7, Mohican Twp., Ashland Co., Ohio
17	P-1434	Martin no. 1	Sun Oil Co.	Sec. 15, Chester Twp., Wayne Co., Ohio
18	P-1233	Bowman no. 1	Sun Oil Co.	Lot 4, Salt Creek Twp., Holmes Co., Ohio

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
19	P-101	Luneman no. 1	Pan American Petroleum Corp.	Sec. 7, North Twp., Harrison Co., Ohio
20	P-955	Mizer Unit no. 1	Stocker & Sitler Inc.	Lot 4, Clay Twp., Tuscarawas Co., Ohio
21	P-1330	Johnson no. 1	Natol Corp.	Monroe Twp., Coshocton Co., Ohio
22	P-1712	Paige no. 1	Kin Ark Oil Co.	Sec. 14, Monroe Twp., Knox Co., Ohio
23	P-2129	Swick no. 1	Lake Shore Pipe Line Co.	Sec. 17, Eden Twp., Licking Co., Ohio
24	P-2051	E. Swetnam Comm. no. 1	Southern Triangle Oil Co.	Lot 5-S, 3rd Qtr., Burlington Twp., Licking Co., Ohio
25	P-2057	Roberts no. 1	Howard Atha	Lot 2, 3rd Qtr., Hartford Twp., Licking Co., Ohio
26	P-19	Reppart no. 1	Pan American Petroleum Corp.	Lot 8, Trenton Twp., Delaware Co., Ohio
27	P-91	Pomeroy no. 1	Gibbs Oil Co.	Sec. 4, Berlin Twp., Delaware Co., Ohio
28	P-31	Heminger no. 1	Humble Oil & Refining Co.	VMS 5088, Jefferson Twp., Logan Co., Ohio

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
29	P-427	Lamp no. 1	L.B. Jackson Co.	Sec. 9, Violet Twp., Fairfield Co., Ohio
30	P-945	Swallow no. 9986	Oil Fuel Gas Co.	Sec. 30, Bristol Twp., Morgan Co., Ohio
31	P-434	Heirs no. 1	Clark Oil & Refining Corp.	Sec. 15, Clear Creek Twp., Fairfield Co., Ohio
32	P-11	Zeigler no. 1	Hammerstone Oil Co. & Hadson Ohio Oil Co.	Sec. 19, Colerain Twp., Ross Co., Ohio
33	P-1222	Hockman no. 1	Dunigan Jr.	Sec. 31, Starr Twp. Hocking Co., Ohio
34	P-14	Cryder no. 1	Hammerstone Oil Co. & Hadson Ohio Oil Co.	Sec. 9, Liberty Twp., Ross Co., Ohio
35	P-4	Bailey no. 1	Cabot Corp. and others	18,712' EL & 26,504' NL of Twp., Jefferson Twp., Adams Co., Ohio
36	P-202	Will no. 1	Young & Henneberger	Sec. 17, Harrison Twp., Scioto Co., Ohio
37	P-117	Wagoner no. 1	B. & E. Oil Inc.	Sec. 6, Walnut Twp., Gallia Co., Ohio

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
38	?	Felty no. 1	Union Carbon Co.	Carter Coordinate 3-W-79, Greenup Co., Kentucky
39	P-1555	Pennington #9021-T	United Fuel Gas Co.	Carter Coordinate 21-T-76, Elliott Co., Kentucky
40	P-17590	White no. 2	Holly Creek Production Corp.	Carter Coordinate 20-0-73, Wolfe Co., Kentucky
41	P-14519	Rice no. 1284	Kentucky-West Virginia Gas	Carter Coordinate 19-P-80, Johnson Co., Kentucky
42	?	Fordson Coal Co. no. 36, #8810	United Fuel Gas Co.	Carter Coordinate 3-H-73, Leslie Co., Kentucky
43	Min-407	Nighbert Land Co. no. 9, #8204	United Fuel Gas Co.	0.9 mile S. 37° 50' 0.54 mile W. 82° 20'
44	BOO-991	Bull Creek Land Co. no. 15, G. W. 1569	Cities Service Oil Co.	2.07 mile S. 38° 15' 2.42 mile W. 81° 40' Peytona District, Boone Co., West Virginia
45	FAY-106	New River-Pocahontas no. 1	United Producing Co.	4.27 mile S. 38° 00' 2.93 mile W. 80° 55' Sewell Mountain District Fayette Co., West Virginia
46	SUM-6	Gwinn no. 1	Anchor Gas Co.	5.67 mile S. 37° 45' 2.17 mile W. 80° 40' Alderson District, Summers Co., West Virginia

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
47	WEB-55	Pardee & Curtin Lumber Co. no. 1	Cramon Stanton Inc.	5.51 mile S. 38^{o} 35' 1.58 mile W. 80^{o} 20' Fork Lick District, Webster Co., West Virginia
48	ROA-1200	United Fuel Gas Co., Tr. 2396, #9375-T	United Fuel Gas Co.	4.03 mile S. 38^{o} 40' 3.67 mile W. 81^{o} 15' Walton District, Roane Co., West Virginia
49	HAN-80	Minesinger no. 1	Humble Oil & Refining Co.	3.05 mile S. 40^{o} 35' 3.02 mile W. 80^{o} 30' Clay District, Hancock Co., West Virginia
50	?	Foley no. 1-A	Benedum Trees Oil Co.	2,500 ft. S. 40^{o} 25', 4,500 ft. E. 80^{o} 20', Washington Co., Pennsylvania
51	?	Monroe no. 1	Huntley & Huntley Inc.	600 ft. S. 40^{o} 25' 3,800 ft. E. 79^{o} 45', Allegheny Co., Pennsylvania
52	IND-411	Bennett no. 4750	Manufactur. Light & Heat Co.	14,900 ft. S. 40^{o} 35' 9,800 ft. W. 79^{o} 05' Indiana Co., Pennsylvania
53	CBA-13	Heidingsfelder no. 1	Pennzoil United Inc.	6,950 ft. S. 40^{o} 20' 4,475 ft. W. 78^{o} 50' Cambria Co., Pennsylvania

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
54	?	Penn Track no. 98	Phillips Petroleum Co.	13,500 ft. N. 40^{o} 05', 5,000 ft. W. 79^{o} 10', Westmoreland Co., Pennsylvania
55	?	Blemle no. 1	Pure Oil Co.	740 ft. S. 41^{o} 35', 7,700 ft. E. 76^{o} 20', Bradford Co., Pennsylvania
56	?	Hindle no. 1	Atlas Exploration Co.	6,700 ft. N. 41^{o} 45', 3,350 ft. W. 80^{o} 05', Crawford Co., Pennsylvania
57	ERI-78	Hoag no. 1	Texaco Inc.	16,800 ft. S. 42^{o} 05', 13,600 ft. W. 79^{o} 45', Erie Co., Pennsylvania
58	?	Harrington no. 1	Wolfe's Head Oil Refining Co.	23,925 ft. S. 42^{o} 15', 1,300 ft. W. 79^{o} 20', Chautauqua Co., New York
59	?	Heron no. 1	Humble Oil & Refining Co.	1.85 miles N. 42^{o} 15', 0.30 miles W. 78^{o} 55', Cattaraugus Co., New York
60	?	Cook no. 2	New York State Natural Gas Corp.	17,100 ft. S. 42^{o} 30', 2,050 ft. W. 78^{o} 10', Allegany Co., New York

APPENDIX A - Continued

Well no.	Permit no.	Well name and number	Operator	Location
61	?	Hargrave no. 1, N-588-S	New York State Natural Gas Corp.	12,650 ft. S. 42^{o} 05', 2,650 ft. W. 77^{o} 25', Steuben Co., New York
62	?	May no. 1	Hanley & Bird	11,500 ft. S. 42^{o} 05', 15,000 ft. W. 76^{o} 50', Chemung Co., New York

APPENDIX B

Depths to formation tops in wells used in constructing cross sections and fence diagrams

Abbreviations:

C - core; S - sample description log; GN - gamma ray-neutron log.

A - absent; AS - at surface; L - Middle Devonian, or older, carbonates beneath the shale section; LO - Lower Olentangy Shale and equivalents; O - Ohio Shale and equivalents; SG - Sonyea and Genesee groups and equivalents; T - Tully Limestone; UO - Upper Olentangy Shale and equivalents.

Well no.	Source of data	O	UO	SG	T	LO	L	Reference (if any)
1	C	AS	A	A	A	61	120	Louden (1965)
2	GN	AS	296	A	A	308	382	
3	GN	AS	1510	A	A	1755	1895	
4	GN, S	549	1700	A	A	1834	1952	
5	GN	305	1069	A	A	1160	1256	
6	GN	294	788	A	A	878	950	
7	GN	273	682	A	A	700	767	
8	GN	AS	A	A	A	340	391	
9	GN	305	680	A	A	695	738	
10	GN	287	669	A	A	688	717	
11	GN	142	500	A	A	526	540	
12	GN	177	540	A	A	568	588	
13	GN	675	1107	A	A	1145	1165	

APPENDIX B - Continued

Well no.	Source of data	O	UO	SG	T	LO	L	Reference (if any)
14	GN	628	1111	A	A	1157	1185	
15	GN	760	1352	A	A	1423	1457	
16	GN	640	1373	A	A	1472	1527	
17	GN	910	1810	A	A	1928	2019	
18	GN	860	2177	A	A	2370	2462	
19	GN, S	1285	3337	3893	A	3965	4087	
20	GN	1169	2866	3217	A	3231	3338	
21	GN	1160	2089	A	A	2239	2287	
22	GN	807	1432	A	A	1523	1543	
23	GN	969	1679	A	A	1800	1828	
24	GN	694	1284	A	A	1362	1386	
25	GN	535	995	A	A	1055	1082	
26	GN	285	698	A	A	733	764	
27	GN	AS	244	A	A	275	290	
28	GN	AS	A	A	A	A	149	
29	GN	131	640	A	A	A	700	
30	GN	1449	2851	A	A	3178	3230	
31	GN	550	1030	A	A	A	1105	
32	GN	360	762	A	A	A	862	
33	GN	1185	1964	A	A	2133	2144	
34	GN	252	690	A	A	A	770	
35	GN	AS	62	A	A	A	98	

APPENDIX B - Continued

Well no.	Source of data	O	UO	SG	T	LO	L	Reference (if any)
36	GN	842	1312	A	A	A	1427	
37	GN	1444	2169	A	A	A	2363	
38	GN	957	1324	A	A	A	1418	
39	GN	929	1244	A	A	A	1279	
40	GN	1222	1422	A	A	A	1462	
41	GN	1170	1658	A	A	A	1815	
42	GN	2591	2792	A	A	A	2813	
43	GN	2954	3848	A	A	A	4210	
44	GN	2100	3838	4418	A	4500	4590	
45	GN	3080?	6586?	7337?	A	?	7766	
46	GN	1920	4752?	5578?	A	6032?	6174	
47	GN	1150?	4092?	5344?	A	5754?	6082	
48	GN	2211	4250	4985	A	5190	5361	
49	GN	?	3420	4262	A	4510	4663	
50	GN	1718	4200?	5427	5722	5800	6008	
51	GN	1912?	4725?	6493	6953	7073	7410	
52	GN	1000?	?	6050?	6900	6914	7560	
53	GN	1690?	?	?	8363	8377	9260	
54	GN	990	?	7023?	A	7582	8337	
55	GN		AS?	?	5855	5970	7677	Wagner (1963)
56	GN	149?	2022	?	A	2600	2820	
57	GN	AS	1870	2417?	A	2471	2700	

APPENDIX B - Continued

Well no.	Source of data	O	UO	SG	T	LO	L	Reference (if any)
58	GN	AS	1638	2295	A	2344	2641	
59	GN	AS	1710	2470	A	2626	2962	
60	GN	AS	945	?	2220	2262	2700	
61	GN	AS	852?	?	3185	3235	3942	
62	GN		AS	?	3010	3195	4250	

REFERENCES CITED

Andrews, E.B., 1870, Report of progress in the second district: Ohio Geol. Survey Rep. Prog., 1869, p. 55-142.

Austin, N.C., 1969, Subsurface Tully Limestone, New York and northern Pennsylvania (abs.): Northeastern Sec., Geol. Soc. America, Albany, New York, p. 2.

Baker, R.C., 1942, The age and fossils of the Olentangy Shale of central Ohio: Am. Jour. Sci., v. 240, p. 137-143.

Bates, T.F., 1957, Black shale: storehouse for uranium: Pennsylvania State Univ. Mineral Industries, v. 26, no. 8, p. 1-3, 5-6.

Buehler, E.J., and Tesmer, I.H., 1963, Geology of Erie County, New York: Buffalo Soc. Sci. Bull., v. 21, no. 3, 118 p.

Caster, K.E., 1934, The stratigraphy and paleontology of northwestern Pennsylvania, Pt. 1: Am. Paleontology Bull., v. 21, nO. 71, 185 p.

Cate, A.S., 1963, Lithostratigraphy of some Middle and Upper Devonian rocks in the subsurface of southwestern Pennsylvania, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey Rept. G39, p. 229-240.

Cooper, G.A., 1930, Stratigraphy of the Hamilton Group of New York, Pt. 1: Am. Jour. Sci., v. 219, p. 214-236.

Cooper, G.A., 1933, Stratigraphy of the Hamilton Group of eastern New York, Pt. 1: Am. Jour. Sci., v. 226, p. 537-551.

Cooper, G.A., 1934, Stratigraphy of the Hamilton Group of eastern New York, Pt. 2: Am. Jour. Sci., v. 227, p. 1-12.

Cooper, G.A., 1941, New Devonian stratigraphic units: Washington Acad. Sci. Jour., v. 31, p. 179-181.

Cooper, G.A., chairman, 1942, Correlation of Devonian sedimentary formations of North America: Geol. Soc. America Bull., v. 53, p. 1729-1794.

Cooper, G.A., and Williams, J.S., 1935, Tully Formation of New York: Geol. Soc. America Bull., v. 46, p. 781-868.

Cushing, H.P., 1912, The age of the Cleveland Shale of Ohio: Am. Jour. Sci., v. 183, p. 581-584.

Dennison, J.M., 1963, Stratigraphy between Tioga Metabentonite and Pocono Formation along Allegheny Front in Maryland and West Virginia, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey, Rept. G39, p. 213-227.

Dennison, J.M., 1970, Stratigraphic divisions of Upper Devonian Greenland Gap ("Chemung Formation") along Allegheny Front in West Virginia, Maryland, and Highland County, Virginia: Southeastern Geology, v. 12, p. 53-82.

Dennison, J.M., and Naegele, O.D., 1963, Structure of Devonian strata along Allegheny Front from Corriganville, Maryland, to Spruce Knob, West Virginia: West Virginia Geol. and Econ. Survey Bull. 24, 42 p.

Donnerstag, Philip, and McDonald, Rosemary, 1952, Sample study and correlation of Robert Bates No. 1 well: New York State Mus. Circ. 30, 10 p.

Donnerstag, Philip, McAuslan, E.R., and Galpin, S.S., 1950, Sample study and correlation of C.C. Lobdell No. 1 well: New York State Mus. Circ. 28, 15 p.

Ellison, R.L., 1963, Faunas of the Mahantango Formation in South-central Pennsylvania, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey, Rept. G39, p. 201-212.

Ellison, R.L., 1965, Stratigraphy and paleontology of the Mahantango Formation in south-central Pennsylvania: Pennsylvania Topog. and Geol. Survey, Rept. G48, 298 p.

Fettke, C.R., 1933, Subsurface Devonian and Silurian sections across northern Pennsylvania and southern New York: Geol. Soc. America Bull., v. 44, p. 601-660.

Fettke, C.R., 1961, Well-sample descriptions in northwestern Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey Bull. M40, 691 p.

Foreman, H.P., 1959, A new occurrence of Devonian Radiolaria in calcareous concretions of the Huron Member of the Ohio Shale (Ohio-Ky.): Jour. Paleontology, v. 33, p. 76-80.

Foreman, H.P., 1963, Upper Devonian Radiolaria from the Huron Member of the Ohio Shale: Micropaleontology, v. 9, 267-304.

Friedman, G.M., and Johnson, K.G., 1966, The Devonian Catskill Delta complex of New York, type example of a "tectonic delta complex," in Shirley, M.L., and Ragsdale, J.A., eds., Deltas in their geologic framework: Houston Geol. Soc., p. 171-188.

Fuller, J.O., 1950, Northern Middle Devonian sedimentary source for the Sharon Conglomerate of northeastern Ohio (abs.): Geol. Soc. America Bull., v. 61, p. 1463-1464.

Gable, K.M., 1973, Conodonts and stratigraphy of the Olentangy Shale (Middle and Upper Devonian), central and southern Ohio: Ohio State Univ., M.S. thesis (unpub.), 90 p.

Grabau, A.W., 1917, Age and stratigraphic relations of the Olentangy Shale of central Ohio, with remarks on the Prout Limestone and so-called Olentangy Shale of northern Ohio: Jour. Geology, v. 25, p. 337-343.

Hass, W.H., 1947, Conodont zones in Upper Devonian and Lower Mississippian formations of Ohio: Jour. Paleontology, v. 21, p. 131-141.

Hass, W.H., 1956, Age and correlation of the Chattanooga Shale and Maury Formation: U.S. Geol. Survey Prof. Paper 286, 47 p.

Heckel, P.H., 1969, Devonian Tully Limestone in Pennsylvania and comparison to type Tully Limestone in New York: Pennsylvania Topog. and Geol. Survey Inf. Circ. 60, 33 p.

Hoover, K.V., 1960, Devonian-Mississippian shale sequence in Ohio: Ohio Geol. Survey Inf. Circ. 27, 154 p.

Huddle, J.W., 1974, Middle/Upper Devonian conodont zonation in western New York (abs.): Geol. Soc. America Abs. with Programs, v. 6, p. 516.

Janssens, A., and de Witt, Wallace, Jr., 1976, Potential natural gas resources in the Devonian shales in Ohio: Ohio Geol. Survey Geol. Note 3, 12 p.

Johnson, J.G., 1971, Timing and coordination of orogenic, epeirogenic, and eustatic events: Geol. Soc. America Bull., v. 82, p. 3263-3298.

Johnson, K.G., and Friedman, G.M., 1969, The Tully clastic correlatives (Upper Devonian) of New York State: a model for recognition of alluvial, dune(?), tidal, nearshore (bar and lagoon), and offshore sedimentary environments in a tectonic delta complex: Jour. Sed. Petrology, v. 39, p. 451-485.

Kindle, E.M., 1912, The stratigraphic relations of the Devonian shales of northern Ohio: Am. Jour. Sci., v. 184, p. 187-213.

Lafferty, R.C., 1941, Central basin of Appalachian geosyncline: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 781-825.

Lamborn, R.E., 1927, The Olentangy Shale in southern Ohio: Jour. Geology, v. 35, p. 708-722.

Lamborn, R.E., 1929, Notes on the character and occurrence of the Olentangy Shale in southern Ohio: Ohio Jour. Sci., v. 29, p. 27-38.

Lamborn, R.E., 1934, Data on the thickness and character of certain sedimentary series in Ohio: Ohio Jour. Sci., v. 34, p. 345-364.

Lewis, T.L., and Schwietering, J.F., 1971, Distribution of the Cleveland Black Shale in Ohio: Geol. Soc. America Bull., v. 82, p. 3477-3482.

Louden, R.O., 1965, The Prout Limestone and Plum Brook Shale; description of lithofacies and discussion of lithostratigraphic relationships with the Olentangy Shale: Bowling Green State Univ., M.S. thesis (unpub.), 112 p.

Martens, J.H.C., 1939, Petrography and correlation of deep-well sections in West Virginia and adjacent states: West Virginia Geol. Survey Rept., v. 11, 255 p.

Martens, J.H.C., 1945, Well sample records: West Virginia Geol. Survey Bull., v. 17, 889 p.

Marten, P., and Nuckols, E.B., 1976, Geology and oil and gas occurrence in the Devonian shales: northern West Virginia, in Devonian shale production and potential: Proceedings of the Seventh Appalachian Petroleum Geology Symposium, Energy Researcj and Devel. Adm., Morgantown Energy Research Center, MERC/SP-76/2, p. 20-40.

McCave, I.N., 1969a, Correlation of marine and nonmarine strata with example from Devonian of New York State: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 155-162.

McCave, I.N., 1969b, Correlation using a sedimentological model of part of the Hamilton Group (Middle Devonian), New York State: Am. Jour. Sci., v. 267, p. 567-591.

Morse, W.C., and Foerste, A.F., 1909, The Waverly formations of east central Kentucky: Jour. Geology, v. 17, p. 164-177.

Morse, W.C., and Foerste, A.F., 1912, The Waverlian formations of east central Kentucky: Kentucky Geol. Survey Bull. 16, serial no. 19, 76 p.

Nelson, B.W., 1955, Pre-Berea mineralogy and stratigraphy: Univ. Illinois, Ph.D. dissert. (unpub.), 104 p.

Newberry, J.S., 1870, Report on the progress of the Geological Survey of Ohio in 1869: Ohio Geol. Survey Rept. Prog. 1869, p. 3-51.

Oliver, W.A., Jr., de Witt, Wallace, Jr., Dennison, J.M., Hoskins, D.M., and Huddle, J.W., 1967, Devonian of the Appalachian basin, United States, in Oswald, D.H., ed., International symposium on the Devonian System, v. 1: Calgary, Alberta, Alberta Soc. Petroleum Geologists, p. 1001-1040.

Oliver, W.A., Jr., de Witt, Wallace, Jr., Dennison, J.M., Hoskins, D.M., and Huddle, J.W., 1971, Isopach and lithofacies maps of the Devonian in the Appalachian basin: Pennsylvania Topog. and Geol. Survey, Prog. Rept. 182, 7 sheets.

Orton, Edward, and others, 1893, Report of the Geological Survey of Ohio: Ohio Geol. Survey, v. 7, 699 p.

Pepper, J.F., and de Witt, Wallace, Jr., 1951, Stratigraphy of the Late Devonian Perrysburg Formation in western and west central New York: U.S. Geol. Survey Oil and Gas Inv. Chart OC 45.

Pepper, J.F., de Witt, Wallace, Jr., and Demarest, D.F., 1954, Geology of the Bedford Shale and the Berea Sandstone in the Appalachian basin: U.S. Geol. Survey Prof. Paper 259, 111 p.

Prosser, C.S., 1903a, The nomenclature of the Ohio geological formations: Jour. Geology, v. 11, p. 519-546.

Prosser, C.S., 1903b, Notes of the Biological Club: Ohio Naturalist, v. 4, p. 47.

Prosser, C.S., 1905, Revised nomenclature of the Ohio geological formations: Ohio Geol. Survey Bull. 7, 36 p.

Provo, L.J., 1977, Stratigraphy and sedimentology of radioactive Devonian-Mississippian shales of the central Appalachian basin: Univ. Cincinnati, Ph.D. dissert. (unpub.), 128 p.

Provo, L.J., Kepferle, R.C., and Potter, P.E., 1977, Three Lick Bed: useful stratigraphic marker in the Upper Devonian shale in eastern Kentucky: Energy Research and Devel. Adm., Morgantown Energy Research Center, MERC/CR-77-2, 56 p.

Ramsey, N.J., 1969, Upper Emsian-upper Givetian conodonts from the Columbus and Delaware limestones and lower Olentangy Shale of central Ohio: Ohio State Univ., M.S. thesis (unpub.), 78 p.

Rickard, L.V., 1964, Correlation of the Devonian rocks in New York State: New York State Mus. and Sci. Service Geol. Survey Map and Chart Ser., no. 4.

Rickard, L.V., 1975, Correlation of the Silurian and Devonian rocks in New York State: New York State Mus. and Sci. Service Map and Chart Ser., no. 24.

Savage, T.E., 1930, The Devonian rocks of Kentucky: Kentucky Geol. Survey, Ser. 6, v. 33, 161 p.

Schwietering, J.F., Neal, D.W., and Dowse, M.E., 1978, Tully (?) Limestone and Hamilton Group in north-central and east-central West Virginia, in Preprints for: Second Eastern Gas Shales Symposium, v. 1: U.S. Dept. of Energy, Morgantown Energy Technology Center, METC/SP-78/6 Vol. I, p. 240-250.

Shaler, N.S., 1877, Notes on the investigations of the Kentucky Geological Survey during the years 1873, 1874, and 1875: Kentucky Geol. Survey Rept. Prog., v. 3, 129-282.

Shepps, V.C., 1963, ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey, Rept. G39, 301 p.

Sloss, L.L., 1963, Sequences in the cratonic interior of North America: Geol. Soc. America Bull., v. 74, p. 93-114.

Sloss, L.L., Krumbein, W.C., and Dapples, E.C., 1949, Integrated facies analysis: Geol. Soc. America, Mem. 39, p. 91-123.

Stauffer, C.R., 1909, The Middle Devonian of Ohio: Ohio Geol. Survey Bull. 10, 204 p.

Stauffer, C.R., 1916, The relationship of the Olentangy Shale and associated Devonian deposits of northern Ohio: Jour. Geology, v. 24, p. 476-487.

Stauffer, C.R., 1938a, Conodonts of the Olentangy Shale: Jour. Paleontology, v. 12, p. 411-443.

Stauffer, C.R., 1938b, The fauna of typical Olentangy Shale: Jour. Geology, v. 46, p. 1075-1078.

Stewart, G.A., and Hendrix, W.E., 1939, Ostracodes as a possible aid in the Olentangy Shale problem (abs.): Geol. Soc. America Bull., v. 50, p. 1988-1989.

Stewart, G.A., and Hendrix, W.E., 1945a, Ostracoda of the Plum Brook Shale, Erie County, Ohio: Jour. Paleontology, v. 19, p. 87-95.

Stewart, G.A., and Hendrix, W.E., 1945b, Ostracoda of the Olentangy Shale, Franklin and Delaware counties, Ohio: Jour. Paleontology, v. 19, p. 96-115.

Sutton, R.G., 1963, Correlation of Upper Devonian strata in south-central New York, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey, Rept. G39, p. 87-101.

Tesmer, I.H., 1963, Geology of Chautauqua County, New York, Part I, stratigraphy and paleontology (Upper Devonian): New York State Mus. and Sci. Service, Bull. 391, 65 p.

Tillman, J.R., 1969, On the age of the Olentangy Shale of central Ohio (abs.): North-central Sec., Geol. Soc. America, Columbus, Ohio, p. 49.

Tillman, J.R., 1970, The age, stratigraphic relationships, and correlation of the lower part of the Olentangy Shale of central Ohio: Ohio Jour. Sci., v. 70, p. 202-217.

Trainer, D.W., Jr., 1932, The Tully Limestone of central New York: New York State Mus. Bull. 291, 43 p.

Twenhofel, W.H., 1931, The building of Kentucky: Kentucky Geol. Survey, Ser. 6, v. 37, 230 p.

Vanuxem, L., 1839, New York Geol. Survey 3rd. Rept., p. 278.

Ulrich, E.O., 1912, The Chattanooga Series with special reference to the Ohio Shale problem: Am. Jour. Sci., v. 184, p. 157-183.

Wagner, W.R., 1963, Correlation of Susquehanna Group in part of northeastern Pennsylvania, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey Rept. G39, p. 63-77.

Wallace, L.G., Roen, J.B., and de Witt, Wallace, Jr., 1977, Preliminary stratigraphic cross section showing radioactive zones in the Devonian black shales in the western part of the Appalachian basin: U.S. Geol. Survey Oil and Gas Inv. Chart OC-80.

Wallace, L.G., Roen, J.B., and de Witt, Wallace, Jr., 1978, Preliminary stratigraphic cross section showing radioactive zones in the Devonian black shales in southeastern Ohio and west-central West Virginia: U.S. Geol. Survey Oil and Gas Inv. Chart OC-83.

Wells, J.W., 1941, Crinoids and Callixylon: Am. Jour. Sci., v. 239, p. 454-456.

Wells, J.W., 1947, Provisional paleoecological analysis of the Devonian rocks of the Columbus region: Ohio Jour. Sci., v. 47, p. 119-126.

Westgate, L.G., 1926, Geology of Delaware County: Ohio Geol. Survey Bull. 30, 147 p.

Wheeler, H.E., 1963a, Post-Sauk and pre-Absaroka stratigraphic patterns in North America: Am. Assoc. Petroleum Geologists Bull., v. 47, p. 1497-1526.

Wheeler, H.E., 1963b, Catskill and the Acadian Discontinuity, in Shepps, V.C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Topog. and Geol. Survey Rept. G39, p. 103-113.

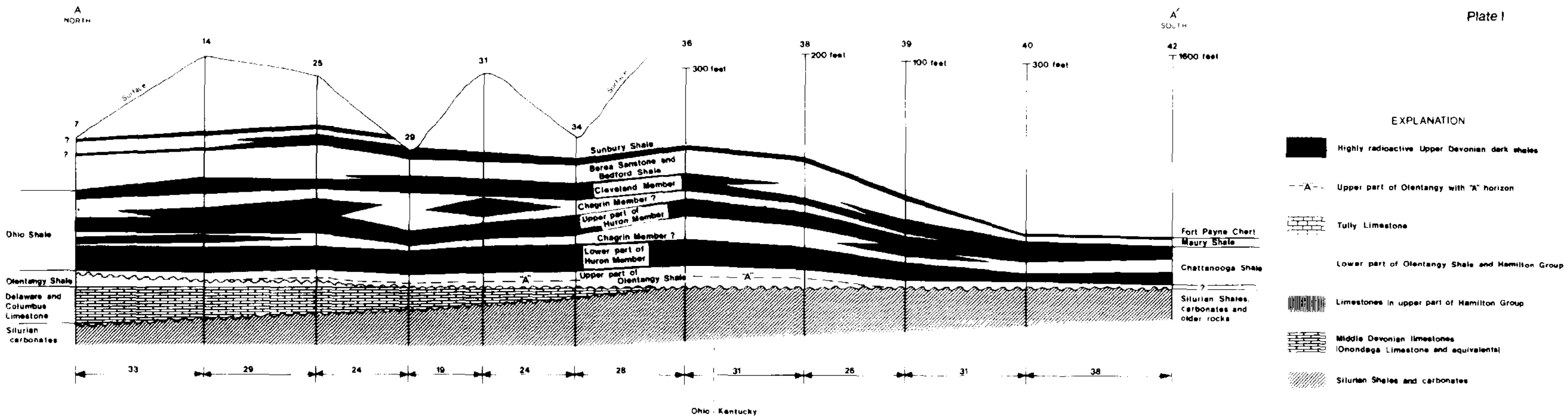
Willard, Bradford, Swartz, F.M., and Cleaves, A.B., 1939, The Devonian of Pennsylvania: Pennsylvania Topog. and Geol. Survey Bull. G19, 481 p.

Winchell, N.H., 1874, Report on the Geology of Delaware County: Ohio Geol. Survey, v. 2, Pt. 1, p. 272-313.

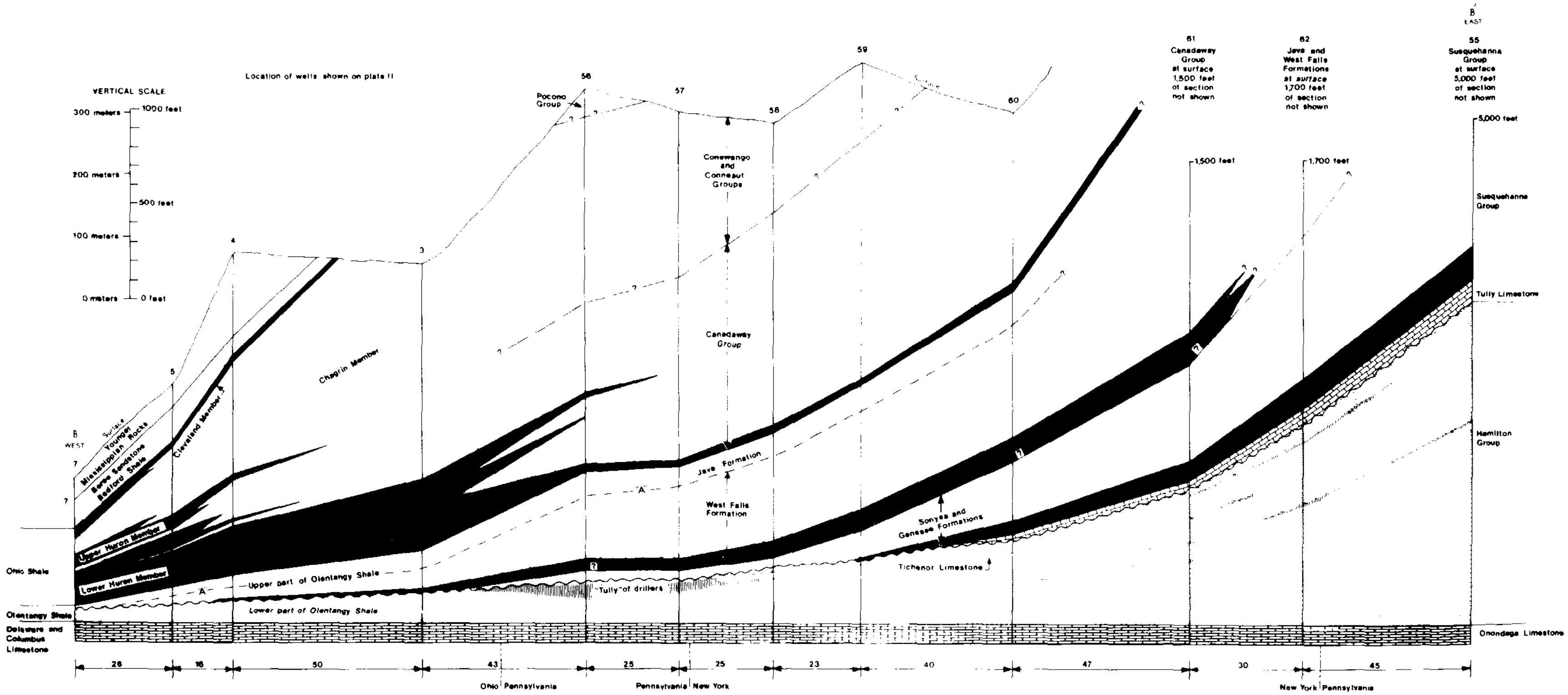
Woodward, H.P., 1943, Devonian System of West Virginia: West Virginia Geol. Survey, v. 15, 655 p.

Wright, N.A., 1973, Subsurface Tully Limestone, New York and northern Pennsylvania: New York State Mus. and Sci. Service, Map and Chart Ser., no. 14, 15 p., 3 pls.

Plate I



Cross-section A-A



Cross-section B-B

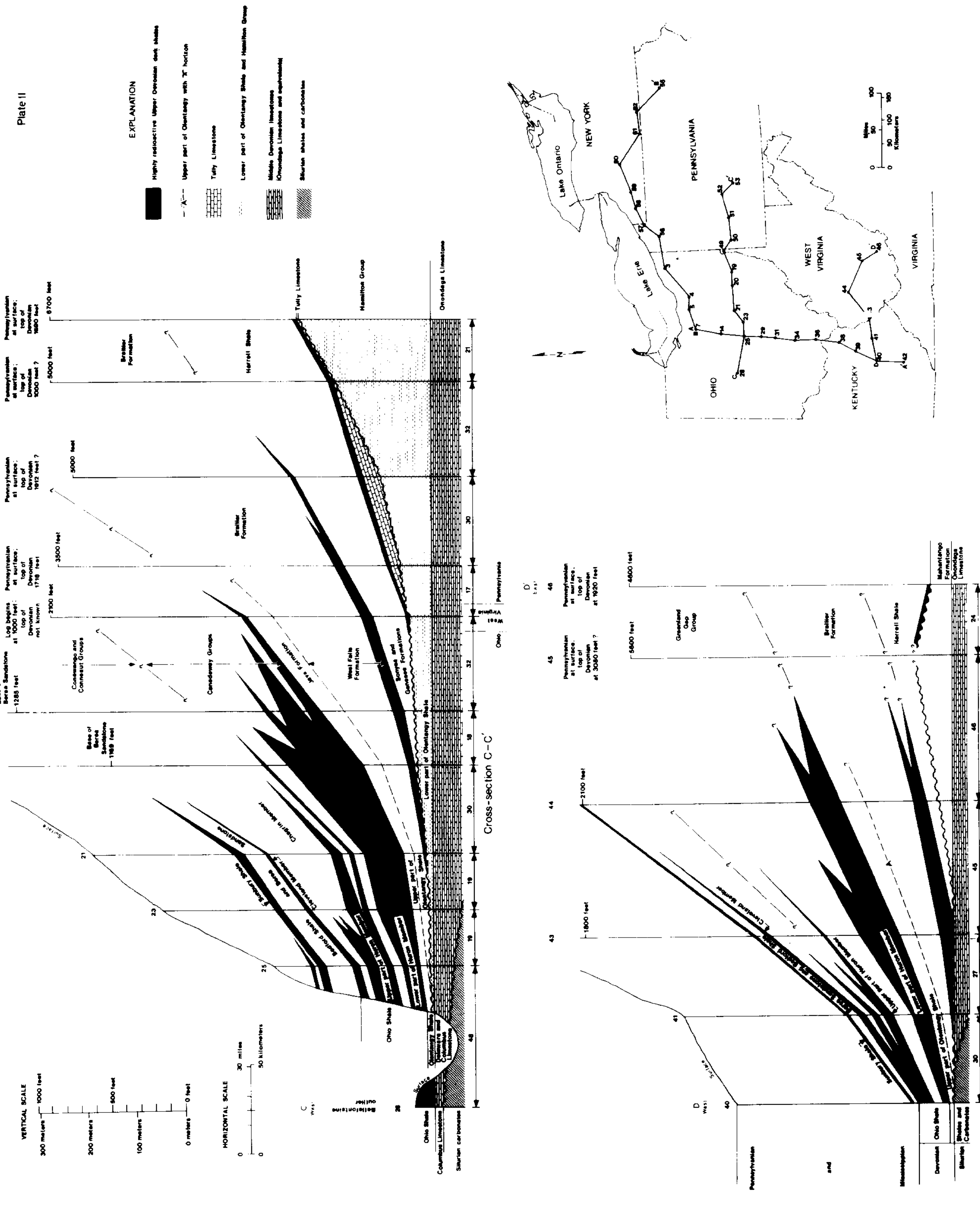


Plate II
EXPLANATION
Cross-section C–C′
Cross-section D–D′
NEW YORK
PENNSYLVANIA
OHIO
WEST VIRGINIA
KENTUCKY
VIRGINIA
Lake Ontario
Lake Erie